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# THE DEVELOPMENT AND QUALIFICATION TESTING OF A LIGHTWEIGHT NET COUCH AND RESTRAINT SYSTEM FOR USE IN THE MERCURY SPACECRAFT

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# THE DEVELOPMENT AND QUALIFICATION TESTING OF A LIGHTWEIGHT NET COUCH AND RESTRAINT SYSTEM FOR USE IN THE MERCURY SPACECRAFT

Prepared by: Douglas J. Geier
Douglas J. Geier
Flight Acceleration Branch

John B. Slight
John B. Slight
Space Medicine

Ralph J. Marak
Ralph J. Marak
Flight Acceleration Branch

Thomas R. Turner
Thomas R. Turner
Crew Equipment Branch

Authorized for Distribution:

Warren Gillespie, Jr.
for Maxime A. Faget
Assistant Director for Engineering and Development

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1. Technical Services Division, Manned Spacecraft Center.

2. Systems Evaluation and Development Division, Manned Spacecraft Center.

3. Aviation Medical Acceleration Laboratory, Naval Air Development Center.

4. Aviation Medical Research Laboratory, Aeronautical Systems Division, Wright-Patterson Air Force Base.

5. Photographic Division, Manned Spacecraft Center.

# TABLE OF CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

Figure | Page

# THE DEVELOPMENT AND QUALIFICATION TESTING OF A LIGHTWEIGHT NET COUCH AND RESTRAINT SYSTEM FOR USE IN THE MERCURY SPACECRAFT


## SUMMARY

To provide a weight and volume savings for long-duration Mercury flights, a light-weight, energy-absorbing, netting-type couch and restraint system was developed, and flight qualified. This system provides comfort and increased mobility for the couch occupant.

Couch components, tests, and results are discussed in this report.

At the completion of the flight qualification program, the system design and test data were presented to the Manager, Mercury Project, and to the Assistant Director for Engineering and Development, Manned Spacecraft Center, and were accepted as a flight system to be used in place of the hard couch for future Mercury flights. However, since the Mercury program was terminated with the MA-9 flight, this system was not used.


## INTRODUCTION

For long-duration flights using a Mercury spacecraft, it was necessary to investigate the possibility of reducing the weight and size of various spacecraft components. Reduction of weight and size of certain components would then permit the use of the additional components mandatory to increase the spacecraft capability for long-duration use.

Since the development of net couches for future spacecraft was underway, the investigations were directed toward their use in the Mercury spacecraft. An evaluation of the deceleration transmission characteristics of nylon and Dacron Raschel netting and Somyk fabric has been completed. This evaluation demonstrated the feasibility of Somyk fabric for use as an energy-absorbing material. Somyk fabric is knitted from predrawn nylon fibers, which will perform a molecular realinement at particular load inputs. This fabric was selected to be used in the development of a net-couch system for use in the Mercury spacecraft and is discussed in this report.

The proper linear tensile strengths of material, which would allow uniform body movement within the available space envelope, were investigated. From this investigation and from a study of the available space envelope a combination of the Somyk fabric and Dacron Raschel netting was found to be necessary to limit the displacement of the astronaut in the Mercury spacecraft during impact loads.

An investigation of the restraint system to be used with the above combination was also performed. Since the original Mercury restraint system has been modified, it was felt that an improvement could be made by the use of the restraint harness developed for the U.S. Air Force B-70 escape capsule. The net combination used in the net couch and the restraint system mentioned above are discussed in greater detail later in this report.

The necessary framework and hardware were designed by members of the Crew Equipment Branch and fabricated by Manned Spacecraft Center shops. A couch and restraint system was validated by a spacecraft water-drop test program with the spacecraft in a single failure mode (landing-bag up) after which a complete flight qualification test program was completed. During the validation and qualification programs, sustained and impact acceleration tests and vibration tests were performed. The couch occupant during the tests was an anthropomorphic dummy weighing 185 pounds. Accelerometers were mounted on the dummy's head, chest, and buttocks; and acceleration time histories of dummy response were recorded.

The couch and restraint system was man-rated for normal missions with human subjects at Wright-Patterson Air Force Base, Dayton, Ohio. After the flight qualification program was completed, the system was presented to the Manager, Mercury Project, and to the Assistant Director for Engineering and Development, Manned Spacecraft Center. Upon this presentation, the complete couch and restraint system was accepted for flight use.

## SYMBOLS AND ABBREVIATIONS

$A_e$ Lateral area, in.$^2$

BY Horizontal direction towards feet

C Diameter of pressure vessel opening, 5.6 in.

EBD Eyeballs down, acceleration direction caused by force vector from feet to head (Headward force)

EBI Eyeballs in, acceleration direction caused by force vector from back to chest (Transverse force)

| | |
|---|---|
| EBL | Eyeballs left, acceleration direction caused by force vector from left to right (Laterial force) |
| EBO | Eyeballs out, acceleration direction caused by force vector from vector from chest to back (Transverse force) |
| EBR | Eyeballs right, acceleration direction caused by force vector from right to left (Lateral force) |
| EBU | Eyeballs up, acceleration direction caused by force vector from head to feet (Tailward force) |
| $G_x$ | Lateral acceleration |
| $G_y$ | Longitudinal acceleration |
| $G_z$ | Transverse acceleration |
| h | Height, in. |
| LX | Horizontal direction to left |
| P | Pressure, lb/sq in. |
| $P_o$ | Atmospheric pressure, 14.7 lb/sq in. |
| $\Delta P$ | Pressure differential, lb/sq in. |
| RX | Horizontal direction to right |
| $R_1$ | Electrical resistance at initial (room) temperature, ohms |
| $R_2$ | Electrical resistance at final (flame) temperature, ohms |
| s | Surface area, sq in. |
| TY | Horizontal direction towards feet |
| $t_1$ | Initial (room) temperature, °C |
| $t_2$ | Final (flame) temperature, °C |
| Z | Vertical direction taken from some reference point in launch vehicle |

| | |
|---|---|
| $\alpha$ | Temperature coefficient, $\frac{\text{ohms}}{\text{ohm}/^\circ\text{C}}$ |
| $\phi$ | $\frac{1}{2}$ arc angle, deg |
| $\sigma$ | Surface tension on net, lb/in. |

## COUCH COMPONENTS

### Couch Frame

The primary considerations in designing the couch frame were weight and adaptability to the Mercury spacecraft. The external size of the couch frame was restricted to that of the original Mercury hard couch. The internal dimensions were as large as possible to provide maximum room for pilot comfort and maximum net area.

The material chosen for frame fabrication was 6061 aluminum alloy heat treated after fabrication to a T6 condition. The frame is of tubular construction except in the area between the hips and shoulders. This tubular cross section consists of three tubes with an outside diameter of $\frac{5}{8}$ inch and a wall thickness of 0.065 inch. The tubes were arranged in a vertical row and connected with 0.093-inch-thick sheet webs. Two mounting pads are located at the bottom (buttocks) end of the frame. The side rails were rough-machined from stock before welding to the tubular sections. These sections have a square cross section with a mount flange extending upward to mate with the side-attaching brackets.

All fabrication was done in specially constructed jigs to control warpage within acceptable tolerances. All welds were designed to develop the full strength of the parent material and were accomplished by using the Heli-Arc method of inert gas shielding. These welds were later X-rayed to check for cracks and/or deficient welds.

Following fabrication, dimensional checks were made to insure that the couch frame was within acceptable tolerances. The frame was then installed in a heavy fixture to prevent warpage during heat treating and was subjected to the following heat treatment:

(1) Anneal at 775° F for 2 hours

(2) Solution treatment at 990° F for 2 hours

(3) Harden at 350° F for 8 hours

Lacing holes were drilled through the web of the tubular section and the flange of the side rails. These holes have a 0.156-inch diameter and are spaced at intervals of approximately $\frac{3}{4}$ inch. Each hole was handworked to provide a smooth opening for the lacing cord to pass through.

To remove surface scratches and finish marks, the two frames designated as flight items were vapor blasted by spraying all external surfaces with a stream of high-pressure water to which a fine abrasive grit had been added. This procedure produces a dull satin finish and cleans areas that are not readily accessible by hand.

A spreader-bar assembly was then installed. This device aids in keeping the couch frame dimensionally stable during shipment, net lacing, and spacecraft installation. The spreader bar must be used because the tension of a laced net causes a lateral deflection of about $\frac{3}{8}$ inch on an unrestrained couch frame. Figure 1 shows the frame with spreader bar in place, and figure 2 shows the frame with Somyk fabric laced into it.

## Lateral Support Pads

The lateral support pads used in the net couch system were designed to protect the couch occupant from injuries resulting from lateral or longitudinal accelerations. Accelerations of this nature are normal and result from a horizontal velocity due to wind drift and impact of the spacecraft at an angle due to parachute swing and/or wave action. These accelerations are of a very short duration and are not expected to exceed 30g under the worst combination of conditions. Therefore, the major concern was to prevent the occupant from hitting any hard, uneven surfaces, such as the couch frame itself.

The pads consist of a two-piece upper fairing fitted to the inside contour of the couch frame and joined at the shoulders. The lower end is contoured for the buttocks and extends to the top of the spacecraft couch-well structure, while the remaining areas serve mainly to cover the couch frame and are faired into the couch-well structure along the sides. An additional fairing under the couch in the buttocks area completes the pad installation.

The pads are of molded construction utilizing a filler of 5 lb/cu ft urethane foam covered with a single layer of fiber-glass cloth. The bonding agent is Epon 828 resin activated by Versamid 125. All materials used in this construction had previously been approved for use in the Mercury spacecraft.

The upper pads are held in place by means of nylon ties which are attached to the couch frame. The lower pad is attached to the couch mounting bracket by means of two no. 10 screws.

## Restraint Harness

Experience gained from previous Mercury space flights indicated the Mercury knee restraints were not needed and would not be used for MA-10 and the chest strap also had been made optional. Therefore, the present mandatory restraint system consists of shoulder harness, lap belt, and crotch V-strap. This system has the advantage of rapid disconnect and egress but is less effective in terms of impact protection. Furthermore, the use of the wide lap belt and the V-strap limits the extent to which the astronaut can rise up in the couch with the restraint system connected. The V-strap is required to prevent the lap belt from riding up over the abdomen as the result of the upward pull of the shoulder harness under EBO acceleration.

It is felt that a substantial improvement was made to the Mercury astronaut restraint system by replacing it with the restraint harness developed for the Air Force B-70 escape capsule. This harness is manufactured by the Pacific Scientific Company, Anaheim, Calif., (Part Number 111011520-0).

## Net and Lacing

A cross section of the net body support is shown in figure 3. It can be seen that the body support is made up of a layer of energy-absorbing Somyk fabric between a top and bottom layer of nylon duck, with a bottom layer of Dacron Raschel netting. The purpose of the Dacron Raschel netting is to limit occupant displacement in the spacecraft and act as a breakout layer when extreme acceleration forces are transmitted through the spacecraft. After breakout of the Dacron Raschel layer, the Somyk fabric begins its molecular realinement and energy absorption. The purpose of the nylon duck is to allow the Somyk fabric to stretch between 2 smooth surfaces. Somyk fabric is manufactured from predrawn nylon fibers. The predrawn fibers are woven into cords and then knitted in a loop patern into a net-type fabric which will start molecular realinement at a particular tensile load. The net, as used in the Mercury couch, has four sections that start the molecular realinement at various tensile loads. The four different net sections have tensile strengths which are dependent on the weight of the head and neck, shoulders, arms and upper torso, pelvic area and the lower torso, thighs, legs, and feet.

The nets are fabricated to the internal size of the framework and have a $\frac{3}{32}$-inch-diameter aircraft cable encased in the edge of the net around its periphery. The nets are assembled on the framework by hand lacing around the aircraft cable and through the frame lacing holes. The tension at which the net is assembled on the framework permits the net to be drum-head tight when the assembly is complete. The lacing cord used is a double strand, 110-pound-test, nylon line and is tied off at every sixth hole.

## TEST PROCEDURES

### Individual Component Tests

Somyk-net static-strength characteristics.- Somyk-net material employed a method of knitting using a link and link stretch of predrawn nylon cords. These cords are made from nylon fibers which have been drawn at the manufacturers and still have some elongation qualities left. As a comparision, the nylon strands which are used in the manufacturer of clothing, parachutes, et cetera, have been completely drawn and have no elongation qualities left.

The basic yarn was braided on specially designed machinery in a solid fashion and in such a manner that there is no center hole. This is required to produce instantaneous response to impact loads. It was also necessary to completely hand test this braid for knots and other defects. It was essential that constant quality control was applied over this phase of the operation. Static-strength tests of the individual Somyk cords used to fabricate the various sections of the Somyk net were conducted on an Instron testing machine. Force-deflection curves obtained during these tests are presented in figure 4. The following average results of ten tests were obtained:

| Net section | Load at stretching point - lbs | Load at breaking point - lbs | Elongation, percent |
|---|---|---|---|
| Head | 3.0 | 8.25 | 203 |
| Shoulder | 3.7 | 11.1 | 215 |
| Pelvic | 4.6 | 12.8 | 206 |
| Buttocks | 5.5 | 15.5 | 205 |

A method was devised of checking the manufacture's approximate specification which were determined from data utilizing a commercial knitters' fabric tester. The Crew Equipment Branch's test technique consisted of mounting a section of the Somyk net in a small pressure vessel. One side of the fabric was held at atmospheric pressure while the pressure on the opposite side was increased internal forces. The pressure vessel test equipment is indicated in figure 5. The test set-up with the net in the inflated position is shown in figure 6. This method of testing is believed to produce more accurate results than those produced by the manufacturer's approximation. The data obtained by using both methods are compared in the table on the following page.

| Section | Crew Equipment Branch Data | | Manufacturers Data | Approximate Difference Between C.E.B. Data and Manufacturers Data Percent |
|---|---|---|---|---|
| | Force/Unit Length at Stretch Point lb/in. | Force/Unit Length at Breaking Point lb/in. | Force/Unit Length at Stretch Point lb/in. | |
| Head | 24.6 | 35.8 | 20 to 22 | 11 |
| Shoulders | 36.1 | 47.2 | 35 to 37 | 0 |
| Buttock | 56.1 | 63.3 | 40 to 42 | 25 |

The calculations used in deriving these data are presented in the appendix, and the force-deflection curves are presented in figure 7.

The differences obtained between the manufacturer's and Manned Spacecraft Center stretch points are due primarily to the methods in testing the net material. It is felt that the method of the manufacturers has been improved upon by Crew Systems Division personnel in the form of the pressure tests previously described.

Tables I to III show the test data taken during the pressure tests and the results of the calculations for each section of the M IV Somyk net.

Somyk net flame characteristics.- Flame-point tests were conducted using the setup shown in figure 8 to determine the flame point of the combination of fabric used in the net couch. A sample cross section was put into a small altitude chamber and evacuated. When this was accomplished, oxygen was released until atmospheric pressure was attained. Voltage was then applied to a nichrome wire which was woven through the sample net. The voltage was increased at regular intervals, and recordings of the voltage and amperage were taken. This process was followed until the net burst into flame. Once the voltage and amperage at this point is known, the resistance can be calculated. From the resistance the flame temperature, $t_2$, can be obtained in °C by the formula,

$$R_2 = R_1 \left[1 + \alpha \left(t_2 - t_1\right)\right]$$

Using this formula, the flame temperature of the net couch was calculated to be 727° F.

B-70 restraint harness.- Since the B-70 harness is an "off-the-shelf" item and has been tested by the manufacturer to meet U.S. Air Force specifications of ultimate loads, functional reliability, and environmental suitability, additional testing was conducted with the harness integrated with the net couch and with the Mercury hard couch for a limited number of tests to obtain control or comparison data. Additional tests conducted included:

(1) Ingress and egress tests

(2) Comfort tests

(3) Sustained acceleration tests with human subjects on the Johnsville Centrifuge to acceleration loads of 9g in the EBO direction.

The results of these tests are presented as advantages and disadvantages of the B-70 harness as compared with the Mercury restraint harness.

The advantages of the B-70 harness are as follows:

(1) The harness provides superior impact protection, including the equivalent of a chest strap in terms of impact load distribution onto the body.

(2) The use of a separate lap belt eliminates the necessity for the V-strap.

(3) The subjective opinion of subjects restrained in a Mercury couch by the two systems is that the B-70 harness is more comfortable than the present system.

(4) With a subject in the complete pressure suit, the B-70 harness allowed greater mobility at the waist because of the lower position of the lap belt.

(5) The B-70 harness weighs 2.7 pounds compared with 3.7 pounds for the lap belt, shoulder harness, and V-strap of the present system.

(6) With a subject in a Mercury pressure suit venting at 10 cu ft/min, the cinched down B-70 harness produced an increase in pressure drop through the suit of 0.5 inch of water compared with 0.7 inch of water for the present system. These amounts are in addition to a pressure drop of 2.2 inches of water for the subject in the couch with no restraint.

(7) If the astronaut disconnects the restraint harness in orbit, the B-70 harness will be much easier to reconnect than the present system.

(8) Since the lap belt and shoulder straps may be released separately, the shoulder straps may be released and the lap belt may be left as a minimal restraint device.

(9) This harness has been developed and tested to meet very demanding U.S. Air Force specifications of ultimate loads, functional reliability, and environmental suitability. It is an "off-the-shelf" item. It may be fitted to the Mercury couch very easily by two simple steps: The shoulder straps are threaded through the present shoulder harness adjustment buckles; the lap-belt device is adapted to the present attachments by means of a short strip of steel twisted 90° from end to end and drilled at each end to receive $\frac{1}{4}$ -inch diameter bolts.

Disadvantages of B-70 harness are as follows:

(1) Since the shoulder straps remain connected to the lap-belt-attachment devices after the harness is disconnected, the astronaut must release the take-up reels and bring his arms under the straps before egressing. This procedure results in an additional 2 seconds of total egress time. Egress tests were run for both types of restraint systems with four subjects in street clothes and one subject in a Mercury pressure suit. The "egress" times were measured from the starting position with the subjects' hands on the control sticks to the end-point position with the subjects' replaced on the control sticks, the harness completely disengaged, and the subject ready to pull himself up out of

the couch. A standard procedure was developed for disconnecting system. The subjects were allowed to practice these procedures several times before time measurements were made. With the B-70 harness, the average disconnect time was 2.9 seconds for the subjects in street clothes and 3.0 seconds for the subject in the pressure suit. With the lap-belt, shoulder-harness, V-strap system, the average disconnect time was 1.07 seconds for the subjects in street clothes and 1.08 seconds for the subject in the pressure suit. The subjects were requested to perform the disconnect maneuver as rapidly as possible, to attempt to beat their own time. Therefore these figures are probably close to the minimum times for most highly motivated subjects. Due to the unavailability of spacecraft, tests were not conducted at the Manned Spacecraft Center. Whether an increase in egress time of 2 seconds is prohibitive is not known, but this disadvantage should be weighed against the advantages cited for the B-70 harness.

(2) A second possible disadvantage of the B-70 harness appears when the restrained subject is in a pressurized suit. At a suit of over 2 psi, the folds in the inflated suit (over the abdomen) press down over the lap-belt release and make it difficult to actuate. Since it is very unlikely that the astornaut will need to release the lap belt while his suit is pressurized, this limitation does not seem to be a consideration.

Many of the advantages and disadvantages of the B-70 harness would be applicable when used with the net body support. Since the spacecraft attachment points for the harness are the same with both couch systems, the B-70 harness was used in conjunction with the net couch. Photographs of the B-70 restraint harness assembled in the net couch and a Mercury hard couch are presented in figures 9 and 10, respectively.

## Complete System Tests

Instrumentation.- Throughout all impact tests, accelerometers were located in the dummy and on the spacecraft as shown in figure 11. Three-directional acceleration time histories were measured at the four locations and recorded. Couch-frame input acceleration time histories were measured without a dummy in the couch and were used as couch-input criterion. Figure 12 shows the position of the couch frame when installed in the spacecraft or test fixtures and the available space between the couch frame and the spacecraft inner pressure bulkhead.

To obtain the dynamic forces on and shortly after impact, CEC accelerometers of the four-active-arm strain-gage type were used. These accelerometers were used in conjunction with wide-band and differential amplifiers, both of which were included in the instrumentation system. The outputs of these amplifiers were passed through low-pass filters to limit the frequency response to either 110 or 130 cps, whichever was the most practical cutoff point depending on conditions and locations of tests. The waveforms were then recorded with CEC-type 5-144 oscillographs. The general setup used for instrumentation during the spacecraft water-drop tests and vibration tests is shown in figure 13.

Sustained acceleration and preloading.- All sustained acceleration testing and system preloading were conducted at the Aviation Medical Acceleration Laboratory, Naval Air Development Center, Johnsville, Pa. Human subjects (185 lb and 210 lb) and anthropomorphic dummies (185 lb) were used as couch occupants. Body displacements were measured at the head, back, and buttocks of the couch occupants. The couch and restraint system were preloaded to the simulated Atlas launch and spacecraft reentry profiles and simulated pad-abort profiles by producing the acceleration time history for the above mentioned on the midarm sling of the AMAL centrifuge. The general setup for these test consisted of a fixture simulating the lower pressure bulkhead below the astronaut in the spacecraft with the net couch installed and mounted on the AMAL midarm sling as shown in figures 14 and 15. The tests in which the launch and reentry profiles were used for preloading produced a maximum body displacement of 2.0 inches. When the tests were completed, the couch occupant returned to within 0.5 inch of his 1g normal position. A displacement of 2.75 inches was recorded when preloading of a simulated pad-abort profile of 20g was applied with a return to within 0.75 inch of the normal 1g position.

Vibration.- The objectives of the vibration tests were to qualify the net couches by checking the structural integrity of both the net material (Somyk fabric) and the couch frame. In addition, information pertaining to the response of a couch occupant subjected to vibration was desired. This information was obtained by monitoring the response of an anthropomorphic dummy restrained in the net couch. The dummy was dressed in a pressure suit for one of the tests.

The tests were conducted at Manned Spacecraft Center. Excitation of the net couch and occupant in each of three mutually perpendicular axes was accomplished individually by means of a Ling 275 electrodynamic shaker and two Ling 310 thrusters (electrodynamic shaker) in a push-pull array in conjunction with an oil-film slip table. An accelerometer mounted on the exciter table served as a control for the displacement and acceleration inputs to the vibration exciters.

Five net couches, with occupants, were subjected to the following sinusoidal vibration environment in each of three mutually perpendicular axes:

| Vibration, cps | Loading |
|---|---|
| 5 to 14 | ±0.3-inch double displacement |
| 14 to 100 | ±3.0g |
| 100 to 500 | ±5.0g |
| 500 to 2,000 | ±10.0g |
| 2,000 to 500 | ±10.0g |
| 500 to 100 | ±5.0g |
| 100 to 14 | ±3.0g |
| 14 to 5 | ±0.3-inch double displacement |

The total sweep time in each axis was 15 minutes.

Visual examination of the net couch after testing revealed no failures of netting or frame construction. Response vibration levels experienced by the dummy restrained in the couch are presented in the data-presentation section of this report. Figure 16 shows the general setup during vibration tests.

Spacecraft water drops.- The spacecraft water drops for the qualification program of the Mercury net couch were conducted at Kemah, Texas.

Thirteen drops were made in this phase of the qualification program. The conditions under which these drops were made are listed in table IV. For these drops, Mercury spacecraft 5 was used. The net seat and attachment hardware were installed into spacecraft 5, and the spacecraft was dropped at an impact velocity of 30 fps. Clay was spread on the spacecraft inner pressure bulkhead under the couch to determine if the subject bottomed against these sections upon impact. The high temperature drop was made at the request of the Mercury project office to see if the interior heat of the spacecraft at reentry would have any effect on the net couch. Hot air was pumped into the spacecraft until the interior air temperature was that of the spacecraft at reentry. Due to instrumentation difficulties occuring during the drop test no valid load data was able to be obtained. The drops were made from a crane.

An anthropomorphic dummy, dressed in a Mercury suit and weighting 185 pounds, was used as the couch occupant in these tests. Photographic coverage of these drops was obtained by three different cameras. One onboard camera and one outboard camera took photographs at 400 frames per second, and one outboard camera took photographs at 45 frames per second. Still photographs were also taken of the net couch in the spacecraft before and after each drop. Photographs of the general dockside setup and internal spacecraft arrangement are shown in figures 17 and 18, respectively.

## PRESENTATION OF DATA

Comparisons between couch-frame input acceleration time histories and maximum dummy response derived from water-impact tests under various conditions are presented in figure 20. Data from single-failure (landing-bag up) drop tests are shown in figures 20A to 20C. Figures Figures 20D to 20F present data derived from normal (landing-bag down) vertical drop tests. Data recorded from single-failure (landing-bag up) water-drop tests with the couch occupant's head up 27°, head down 27°, and side down 27°, are presented in figures 20G to 20I. The spacecraft drop tests were conducted with variations in net preloading, vibration testing, and spacecraft-impact angle. The results of the vibration tests are shown in figure 21.

Samplings of the dummy response data recorded during the vibration tests are presented in figures 28 to 30. Accumulated data from human drop tests conducted at Aeronautical Systems Division, Wright-Patterson Air Force Base, Dayton, Ohio, to man-rate the net couch and restraint system for normal missions are presented in table V. This data shows the impact loads and the loads transmitted to the man. Even though this data shows amplification of the impact loads, the loads transmitted to the subject are well within acceptable tolerance levels. No amplification of the loads occur at peak loading conditions as can be seen from the recordings of the dummy response data previously mentioned.

## CONCLUDING REMARKS

The net couch and restraint system has been subjected to sustained acceleration, vibration, and impact tests, with both human subjects and a 185-pound dummy. The tests in which human subjects were used "man-rated" the net-couch system for the normal mission impact-bag-down water-landing and also for the bag-down land-landing. The probably acceptability of the impact-bag-up water-landing (a single-failure mode) was determined from the dummy drop tests outlined below.

The B-70 restraint harness has definite advantages over the present Mercury restraint system in respect to impact protection, comfort mobility, weight, suit-vent back pressure, versatility, and ease of reconnection. It is an "off-the-shelf" item and can be mated to the original Mercury harness attachment points very quickly. However, the B-70 harness requires about 2 seconds more to disconnect than the present system, and the lap belt can be released only with difficulty when the suit is inflated to above 2 psi.

A total of 22 drop tests were conducted using a 185-pound dummy or human subjects on the net couch. Five additional tests were made using the present Mercury rigid couch to obtain a comparison between it and the net couch. These tests may be divided into three categories:

1. Net couch drops on water using anthropomorphic dummy.

2. Rigid couch drops on water and on the CSD drop tower.

3. Net couch drops on the Wright-Patterson Air Force Base drop tower.

   a. Twelve drop were made at Clear Lake with the net couch installed in Spacecraft 5. The occupant was a 185 pound dummy. The impact velocity for each of these tests was approximately 30 feet per second. The following tabulation is the result of these drops.

| Dummy Orientation (Spacecraft impact angle) | Number of Drops | Maximum Forward Acting Force on Dummy g |
|---|---|---|
| 0° - vertical drop | 7 | 35 |
| Head down approximately 27° | 2 | 29 |
| Head up approximately 27° | 2 | 16 |
| Side down approximately 27° | 1 | 24 |

The lateral, headward and tailward forces accompanying these forward acting forces all appear to be within acceptable limits. The implications of these drops are discussed later.

   b. Four drops were made at Clear Lake, using the Mercury hard couch in place of the net couch, in order that the accentuations on the dummy could be compared with those gathered on the net couch for the respective drops. The honeycomb used for these drops was taken from either a back-up spacecraft or from storage. During the water drops, although the impact velocity was 30 feet per second the honeycomb did not crush. This is felt to be due to the fact that only 20 feet per second velocity is taken out by the spacecraft going under water slowly. To test this assumption a drop was made on the CSD drop tower in such a manner that the full 30 feet per second would be taken out during the initial impact and in this case the honeycomb did crush 2 inches. In general, these tests indicate that the net couch takes out the initial high spike that is characteristic of honeycomb attenuation. The acceleration levels measured on the dummy on the net couch were consistently lower than the accelerations measured during the drops on the rigid system, all other conditions being the same.

c. Eight drops were made on the Wright Patterson Air Force Base drop tower using human subject and the net couch. Beginning at very low levels, W-P worked up to 19g, 20 feet per second level.

Based on the g versus time histories of the impact of the Mercury spacecraft, there are these general situations that must be considered in evaluating the net couch and restraint system.

1. Normal mission: (Impact-bag-down water landing and impact-bag-down land landing.) The net couch has been man-rated by the human drops at Wright Patterson Air Force Base, Dayton, Ohio, for both of these cases.

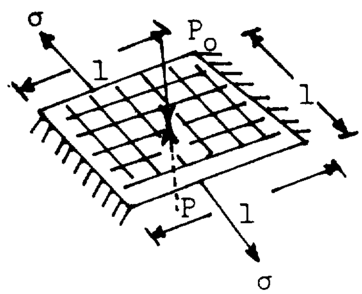
2. Single failure mode: (Impact-bag-up water landing.) Based on the dummy drops conducted at Clear Lake, it is felt that the occupant will not bottom out and that if an injury were to be sustained it would be minor.

3. Double failure mode outside mission requirements: (Impact-bag-up land landing.) The last drop in the test series was to help define this condition. The dummy bottomed onto the inner pressure bulkhead and dummy responses recorded indicated high spike-type accelerations. Under these conditions injury would occur.

# APPENDIX

## Assumptions For Static Net Tests

1. A unit area of net is rigidly attached on two sides, and a unit force is applied to the free sides.



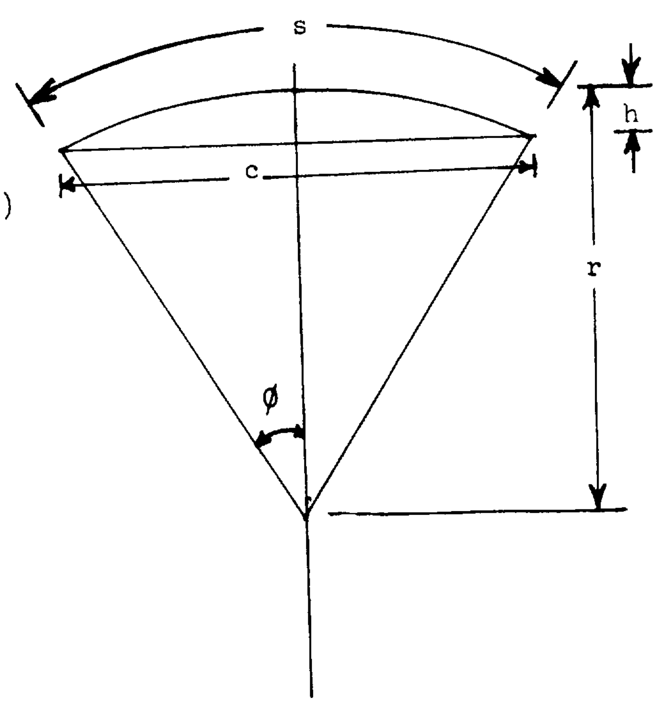

2. The net during expansion has the shape of a portion of a sphere and at its breaking point the net has the shape of a sphere.

$A_l = 2\pi rh$ (1)

$S = \frac{2\pi r\phi}{180}$ (2)

$\gamma = \sqrt{\frac{1}{4} c^2 + (r-h)^2}$ (Ref. 1) (3)

$\tan\theta = \frac{c}{2}(r-h)$ (4)




Since:

$\Sigma F = 0$

Therefore:

$PA_l = P_oA_l + 2\sigma S$ (5)

Solving for $\sigma$, and using $P-P_o = \Delta P$, then

$$\sigma = \frac{A_l \Delta P}{2S} \tag{6}$$

combining with (1)

$$\sigma = \frac{\pi r h \Delta P}{S} \tag{7}$$

combining with (3) and (2)

$$\sigma = \frac{90\ \Delta P h}{\phi} \tag{8}$$

combining with (4)

$$\sigma = \frac{90\ h\Delta P}{\tan^{-1}\left(\frac{4ch}{c^2} - 4h^2\right)} \tag{9}$$

Tables I to III show the test data taken during the pressure tests and the results of the calculations for each section of the Somyk net.

## REFERENCES

1. Marks Mechanical Engineering Handbook. Sixth Edition, 1958, New York, N. Y., Sec. 2, p. 17.

2. Eiband, A. Martin: Human Tolerance to Rapidly Applied Accelerations- A Summary of the Literature. NASA MEMO 5-19-59E, 1959.

3. Pesman, G. J.: Normal Mission Limits. NASA-MSC S-299-11.

TABLE I.- PRESSURE DATA FOR HEAD SECTION

| $\Delta P$, psi | h, in. | $h^2$, in.$^2$ | 22.4h | $31.36-4h^2$ | $\frac{22.4h}{31.36-rh^2}$ | $\phi$, deg | $90h\Delta P$ | $\sigma$, lb/in. |
|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 31.36 | ~ | ~ | 0 | 0 |
| 2.5 | 1.05 | 1.103 | 23.52 | 26.94 | .8731 | 41.1 | 236.25 | 5.75 |
| 5 | 1.35 | 1.823 | 30.24 | 24.07 | 1.2563 | 51.4 | 607.5 | 11.81 |
| 7.5 | 1.55 | 2.403 | 34.27 | 21.75 | 1.5756 | 57.6 | 1046.25 | 18.15 |
| 10 | 1.75 | 3.063 | 39.20 | 19.11 | 2.0513 | 64.0 | 1575.0 | 24.61 |

Burst Point

$\Delta P = 10$ psi

$h = 7.9 - .75 = 7.15$ in.

$h^2 = 51.0$ sq ft

$\phi = 180°$

$$\sigma = \frac{90h\Delta P}{\phi}$$

$$\sigma = \frac{90(7.15)(10)}{180}$$

$$\sigma = 35.8 \text{ lb/in.}$$

TABLE II.- PRESSURE DATA FOR SHOULDER SECTION

| $\Delta P$, psi | $h$, in. | $h^2$, in.$^2$ | $22.4h$ | $31.36-4h^2$ | $\frac{22.4h}{31.36-rh^2}$ | $\phi$, deg | $90h\Delta P$ | $\sigma$, lb/in. |
|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 31.36 | ~ | ~ | 0 | 0 |
| 2.5 | 1.05 | 1.10 | 23.52 | 26.96 | .8724 | 41.1 | 236.25 | 5.75 |
| 5.0 | 1.25 | 1.56 | 28.00 | 25.12 | 1.1146 | 48.1 | 562.5 | 11.69 |
| 7.5 | 1.50 | 2.25 | 33.60 | 22.36 | 1.5027 | 56.4 | 1012.5 | 17.95 |
| 10.0 | 1.55 | 2.40 | 34.72 | 21.76 | 1.5956 | 57.9 | 1395.0 | 24.09 |
| 12.0 | 1.95 | 3.80 | 43.68 | 16.16 | 2.7030 | 69.7 | 2106.0 | 30.22 |
| 14.0 | 2.15 | 4.62 | 48.16 | 12.88 | 3.7391 | 75.0 | 2709.0 | 36.12 |

Burst Point

$\Delta P = 14.0$ psi

$h = 7.5 - .75 = 6.75$ in.

$\phi = 180°$

$$\sigma = \frac{90\Delta Ph}{\phi}$$

$$\sigma = \frac{90(14)(6.75)}{180}$$

$$\sigma = 47.2 \text{ lb/in.}$$

TABLE III.- PRESSURE DATA FOR BUTTOCK SECTION

| $\Delta P$, psi | h, in. | $h^2$, in.$^2$ | 22.4h | $31.36-4h^2$ | $\frac{22.4h}{31.36-rh^2}$ | $\phi$, deg | $90h\Delta P$ | $\sigma$, lb/in. |
|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 31.36 | ~ | ~ | 0 | 0 |
| 2.5 | 1.00 | 1.00 | 22.4 | 27.36 | .8187 | 39.2 | 225.0 | 5.75 |
| 5.0 | 1.15 | 1.323 | 25.76 | 26.07 | .9881 | 44.6 | 517.5 | 11.60 |
| 7.5 | 1.25 | 1.563 | 28.00 | 25.11 | 1.1151 | 48.1 | 843.75 | 17.54 |
| 10.0 | 1.45 | 2.103 | 32.48 | 22.95 | 1.4153 | 54.8 | 1305.0 | 23.81 |
| 12.0 | 1.50 | 2.250 | 33.60 | 22.36 | 1.5027 | 56.4 | 1620.0 | 28.72 |
| 14.0 | 1.55 | 2.403 | 34.72 | 21.75 | 1.5963 | 57.9 | 1953.0 | 33.73 |
| 16.0 | 1.75 | 3.063 | 39.20 | 19.11 | 2.0513 | 64.0 | 2520.0 | 39.38 |
| 18.0 | 1.85 | 3.423 | 41.44 | 17.67 | 2.3452 | 66.9 | 2997.0 | 44.80 |
| 20.0 | 2.00 | 4.00 | 44.80 | 16.36 | 2.7384 | 69.9 | 3600.0 | 51.50 |
| 22.0 | 2.05 | 4.203 | 45.92 | 14.55 | 3.1560 | 72.4 | 4059.0 | 56.06 |

Burst Point

$\Delta P = 22$ psi
$h = 6.5 - .75 = 5.75$ in.
$\phi = 180°$

$$\sigma = \frac{90h\Delta P}{\phi}$$

$$\sigma = \frac{90(5.75)(22)}{180}$$

$$\sigma = 63.3 \text{ lb/in.}$$

TABLE IV.- DROP ATTITUDE AND CONDITION OF NET FOR SPACECRAFT WATER DROPS

| Test no. | Impact bag | | Impact attitude | | | | Net pre-load | | Vibration | | High temperature | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Up | Down | Vertical | Head up 27° | Head down 27° | Side up 27° | Launch and reentry | Pad abort | Yes | No | Yes | No | |
| 1 | X | | X | | | | X | | | X | | X | |
| 2 | | X | X | | | | X | | | X | | X | |
| 3 | X | | | X | | | X | | | X | | X | |
| 4 | X | | | | X | | X | | | X | | X | |
| 5 | X | | | | | X | X | | | X | | X | |
| 6 | X | | X | | | | X | | | X | | X | Variation in net configuration |
| 7 | X | | X | | | | X | | X | | | X | |
| 8 | X | | X | | | | X | | X | | | X | |
| 9 | X | | X | | | | X | | X | | | X | |
| 10 | | X | X | | | | X | | X | | | X | |
| 11 | X | | X | | | | | X | | X | | X | |
| 12 | | X | X | | | | | X | | X | | X | |
| 13 | X | | X | | | | X | | X | | X | | Instrumentation Difficulties giving erronous data |
| 14 | X | X | X | | | | | | X | | | X | Land drop |

TABLE V.- ACCUMULATED DATA FROM HUMAN DROP TESTS PERFORMED IN MAN RATING THE NET SEAT FOR NORMAL MISSIONS

| Test Conditions | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Drop number | 1086 | 1087 | 1088 | 1089 | 1090 | 1091 | 1092 | 1093 |
| Date | 5/9/63 | 5/9/63 | 5/9/63 | 5/13/63 | 5/13/63 | 5/14/63 | 5/14/63 | 5/14/63 |
| Plunger number | 46 | 46 | 46 | 46 | 46 | 46 | 46 | 46 |
| Drop height, in. | 10 | 24 | 30 | 40 | 50 | 56 | 61 | 68 |
| Location of Accelerometer – Center of Gravity of Carriage | | | | | | | | |
| $\Delta V$, ft sec | 8.5 | 12.25 | 13.5 | 15.2 | 16.68 | 17.7 | 18.5 | 20.3 |
| Peak acceleration, g | 4.25 | 6.33 | 9.65 | 12.7 | 15.6 | 16.8 | 18.1 | 19.1 |
| Pulse duration, msec | 116 | 42 | 56 | 41 | 49 | 40 | 39 | 36 |
| Total duration, msec | 381 | 420 | 477 | 556 | 571 | 605 | 624 | 628 |
| Tail-off duration, msec | 240 | 180 | 214 | 225 | 316 | 338 | 193 | 300 |
| Rate of onset, g/sec | 307 | 880 | 742 | 785 | 1,030 | 1,120 | 1,100 | 1,590 |
| Rate of decay, g/sec | 52 | 376 | 224 | 757 | 790 | 820 | 980 | 1,190 |
| Location of Accelerometer – Chest | | | | | | | | |
| Peak acceleration, g | 5.95 | 9.23 | 11.4 | 12.82 | 19.5 | 17.7 | 22.1 | 19.0 |
| Pulse duration, msec | 117 | 79 | 60 | 85 | 68 | 43 | 44 | 44 |
| Total duration, msec | 371 | 450 | 503 | 518 | 600 | 633 | 653 | 660 |
| Tail-off duration, msec | 350 | 150 | 278 | 250 | 245 | 262 | 276 | 275 |
| Rate of onset, g/sec | 183 | 420 | 556 | 543 | 1,350 | 1,310 | 885 | 1,730 |
| Peak delay, g/sec | 56 | 39 | 33 | 43 | 35 | 27 | 33 | 21 |
| Amplification, percent | 40 | 46 | 18.7 | .78 | 25 | 5.3 | 22.2 | -.52 |

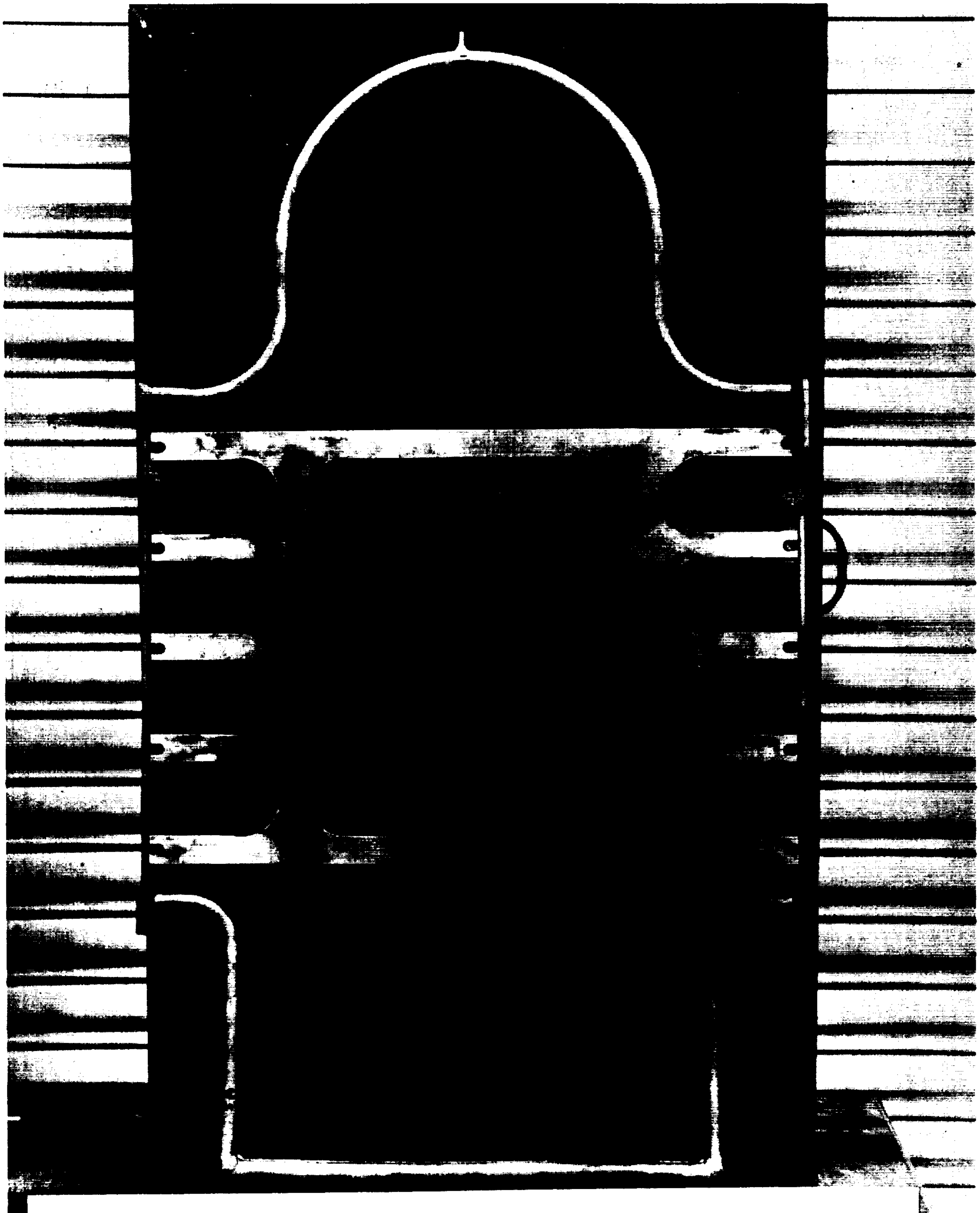


Figure 1.- Couch frame with spreader bar attached.

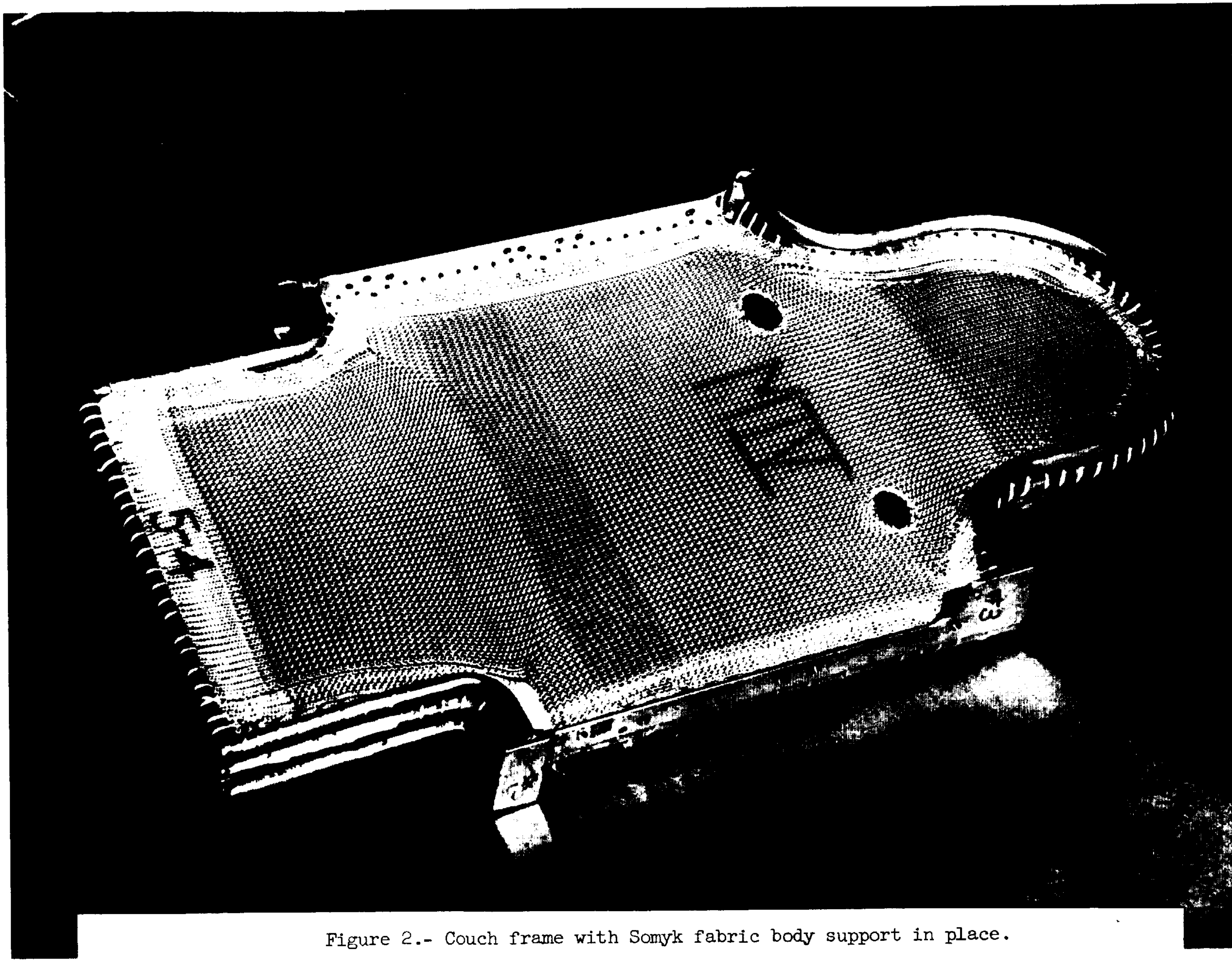


Figure 2.- Couch frame with Somyk fabric body support in place.

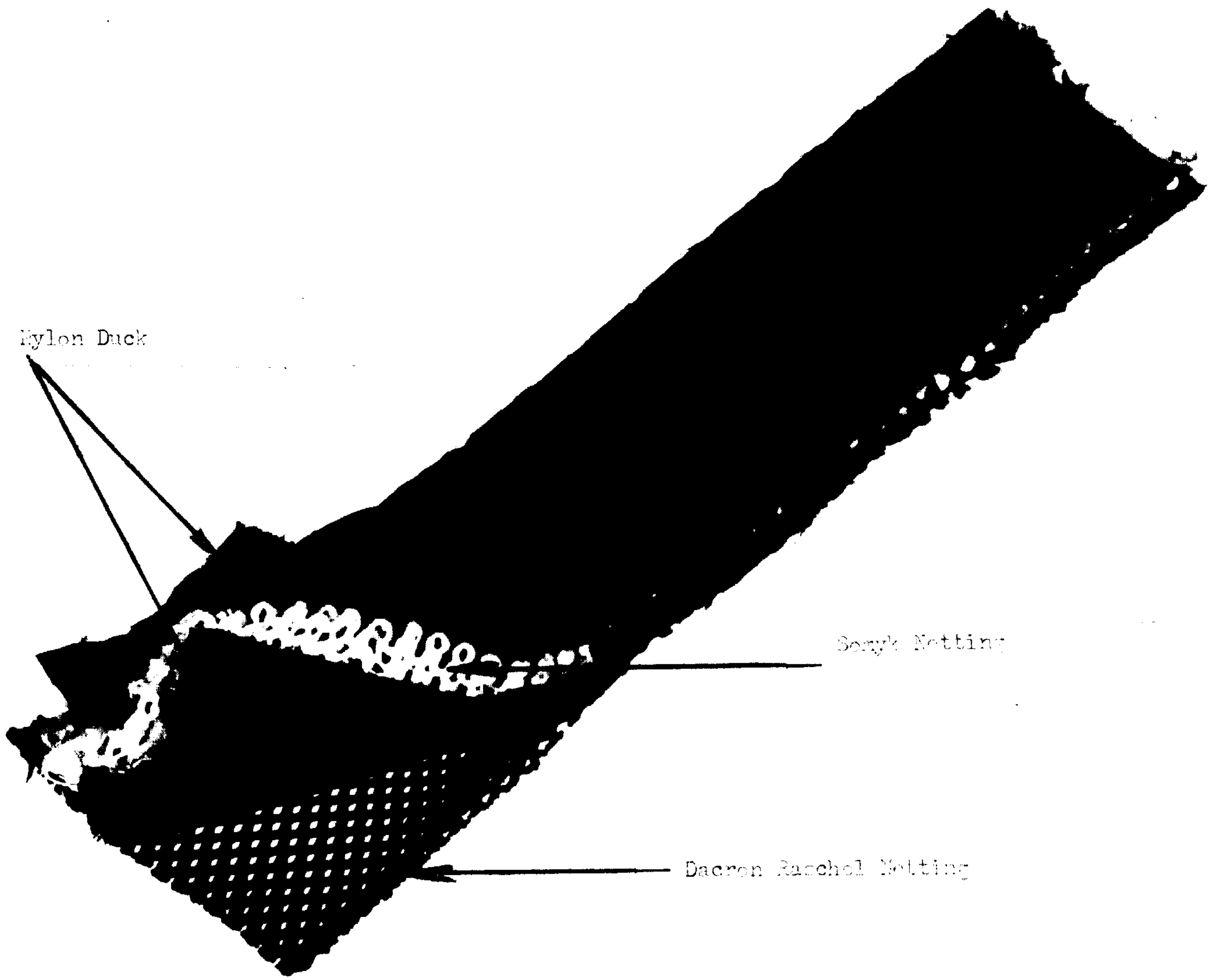



Figure 3.- Cross section of net couch showing various components.

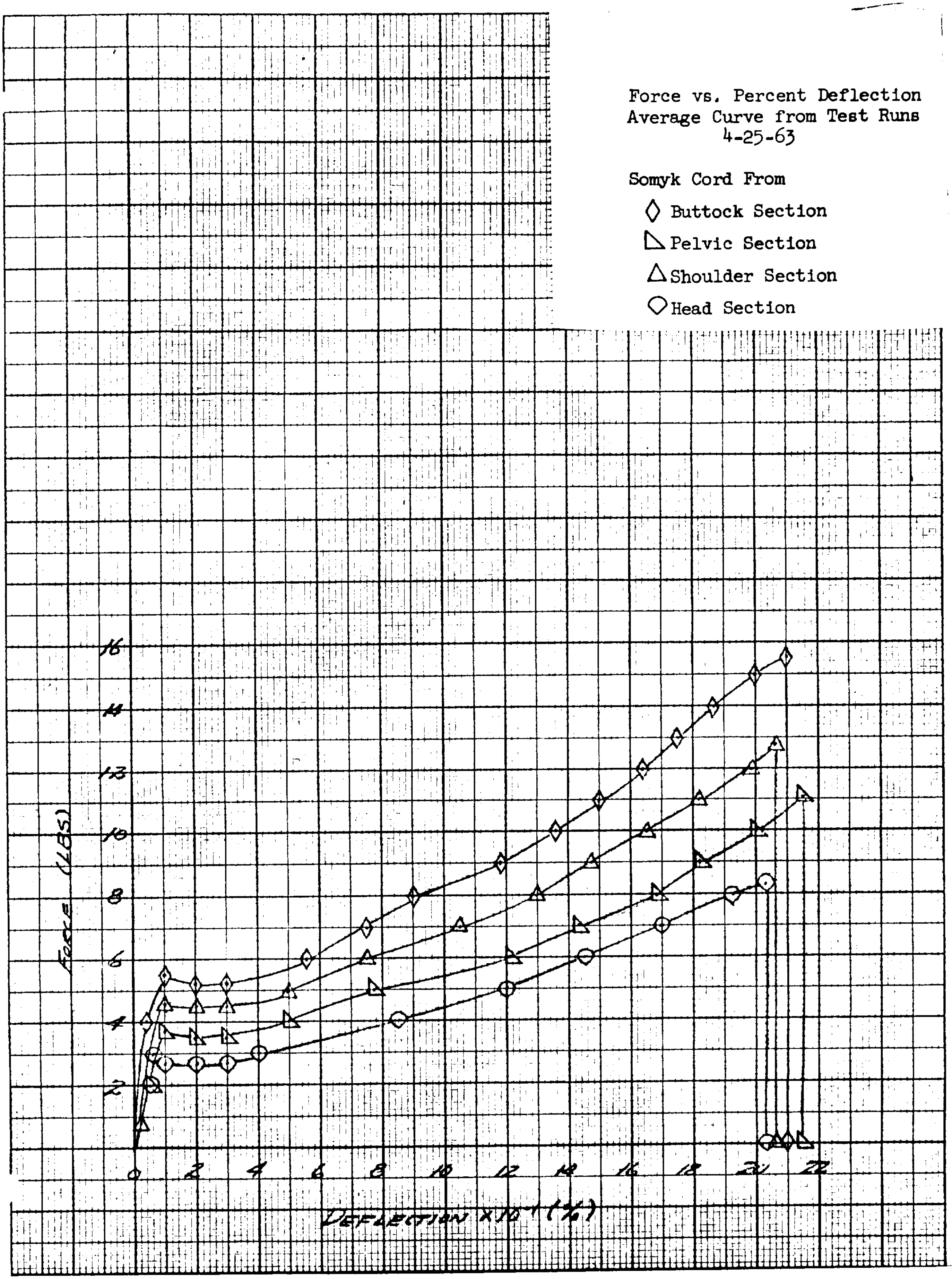



Figure 4.- Force-deflection curves of different Somyk cords used throughout netting.

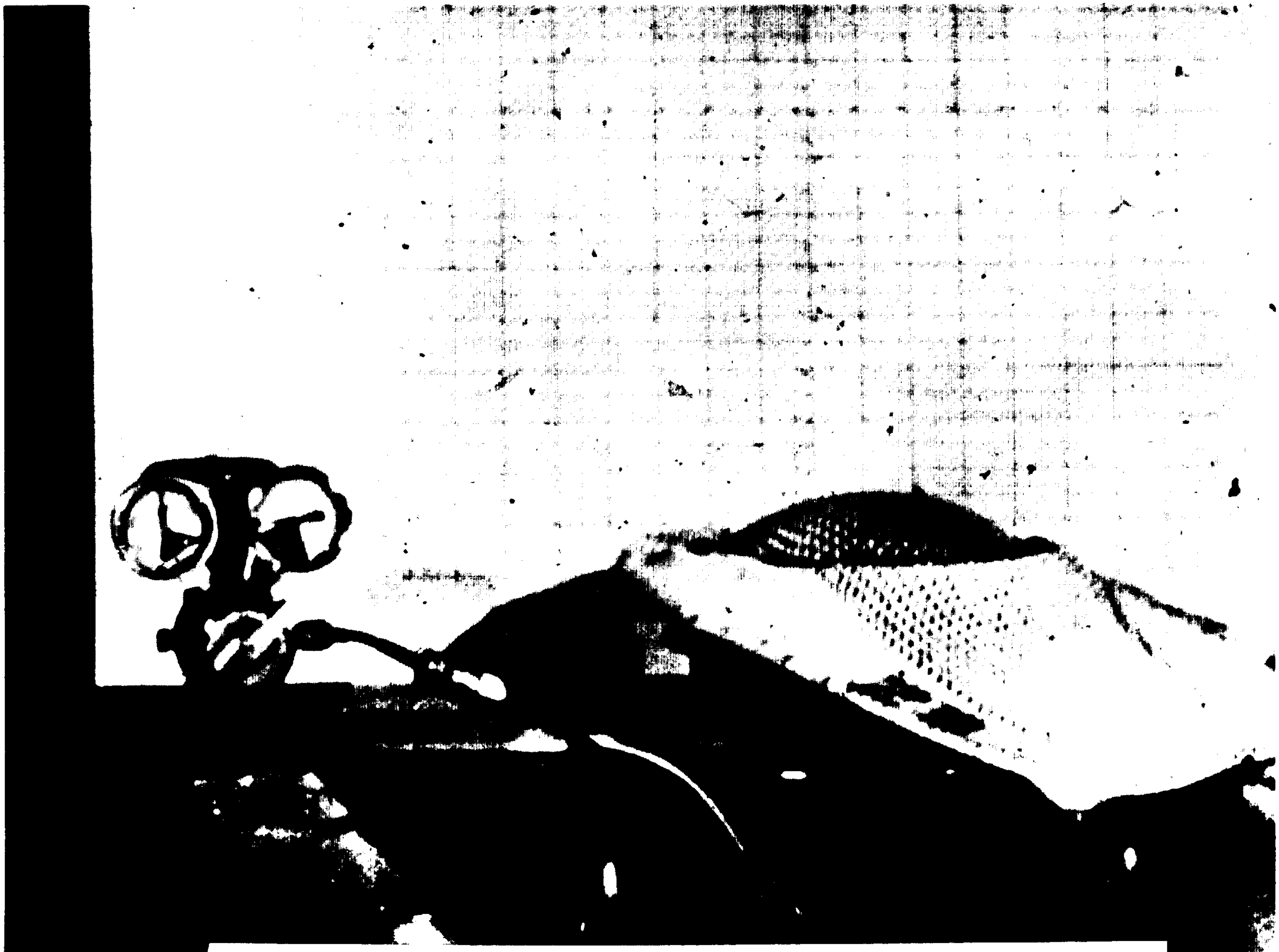


Figure 5.- Pressure vessel test equipment.

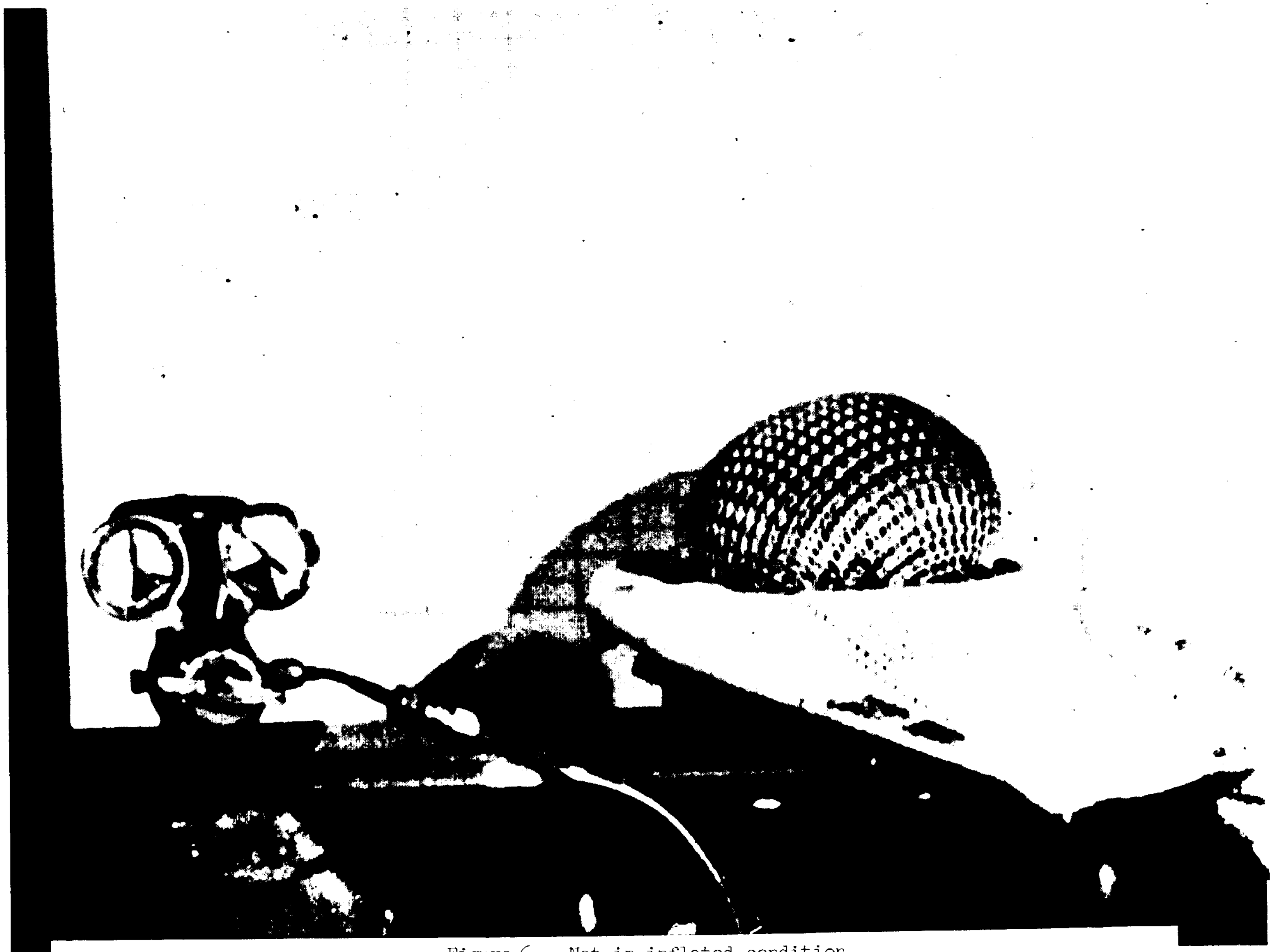


Figure 6.- Net in inflated condition.

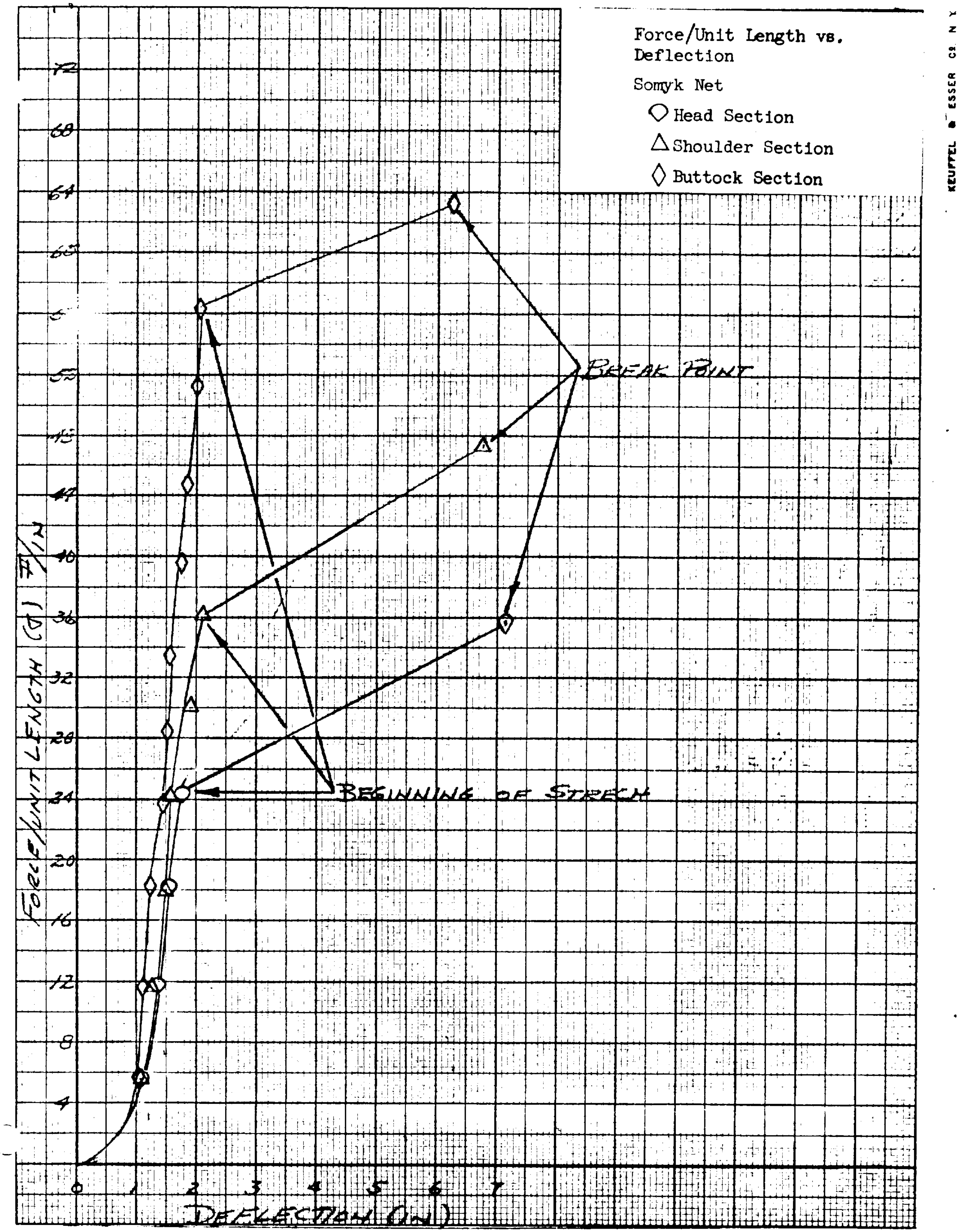



Figure 7.- Force-deflection curves of different strength nettings used.

Figure 8.- General setup for flame tests.

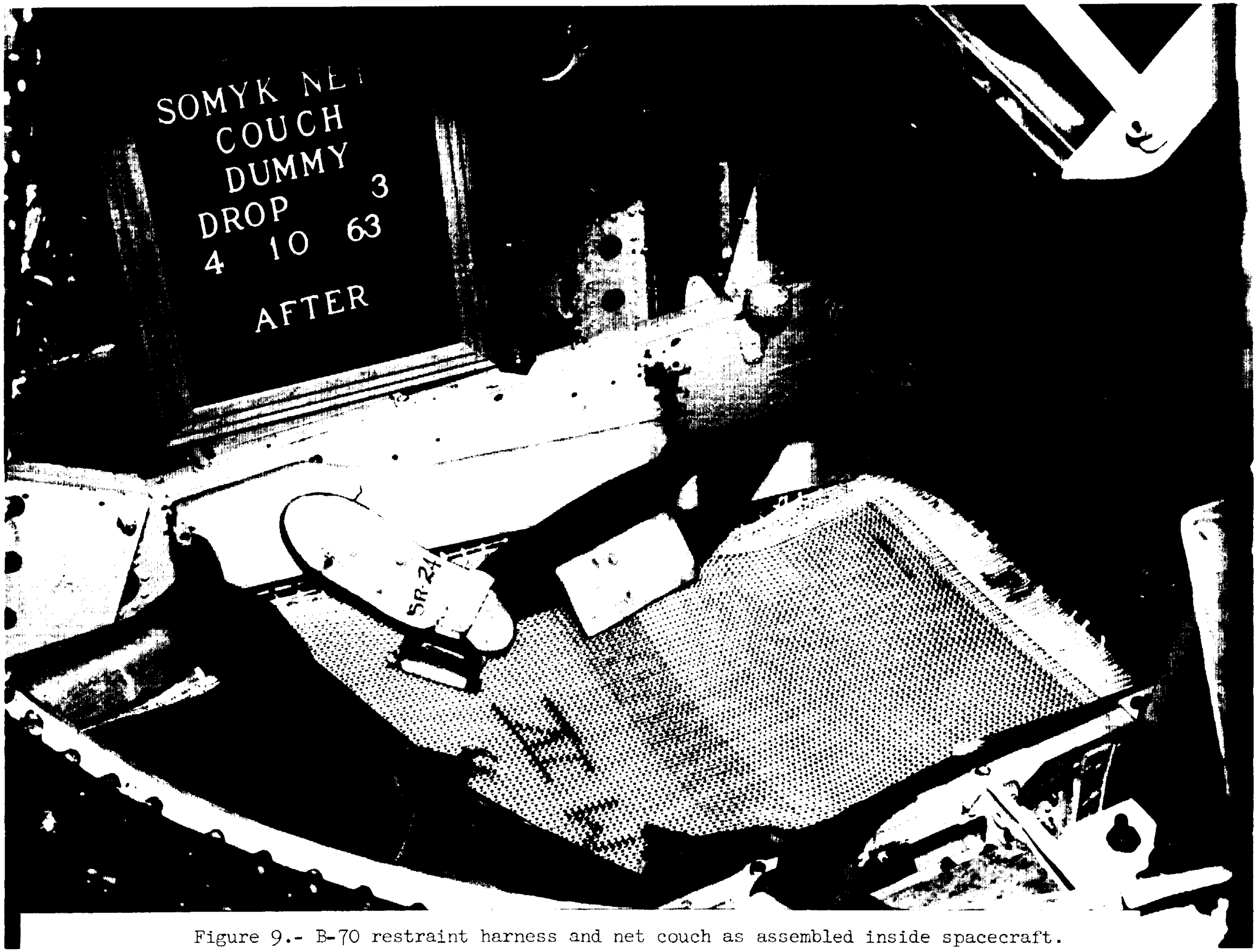



Figure 9.- B-70 restraint harness and net couch as assembled inside spacecraft.

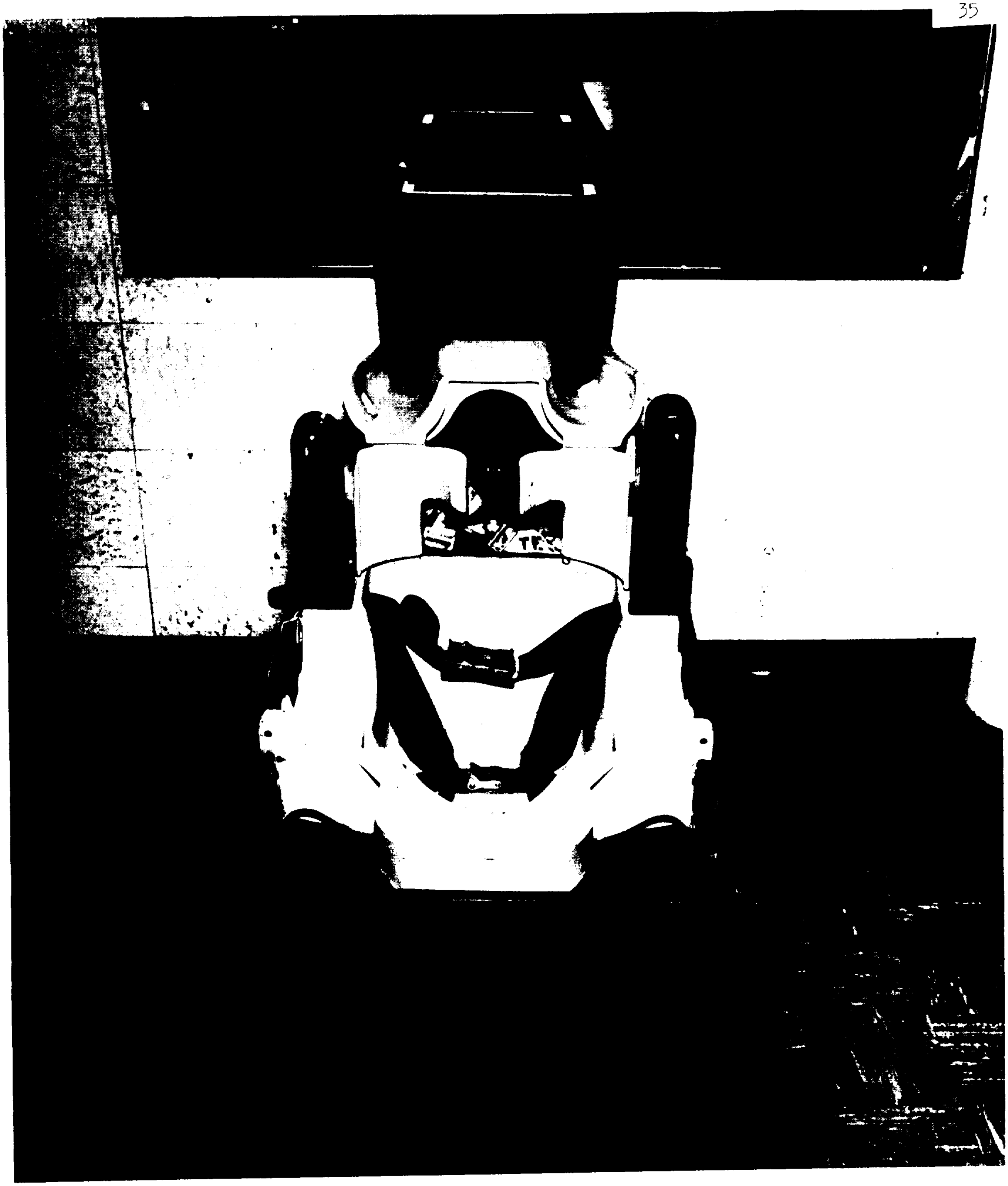


Figure 10.- B-70 restraint harness shown here as assembled in Mercury hard seat mock-up.

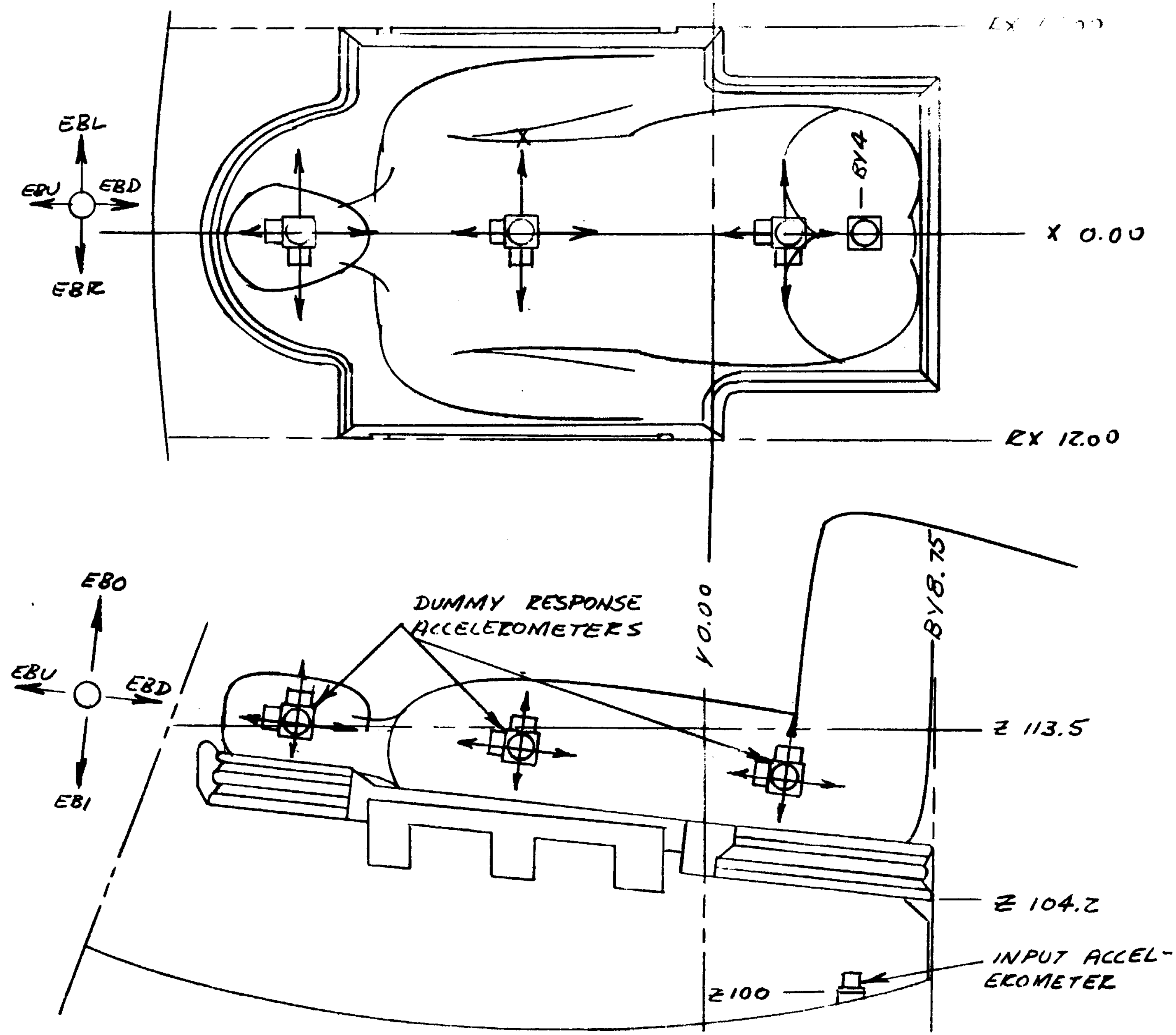



Figure 11.- Accelerometer mounting positions for input and dummy response (X, Y, Z directions); net couch qualification program.

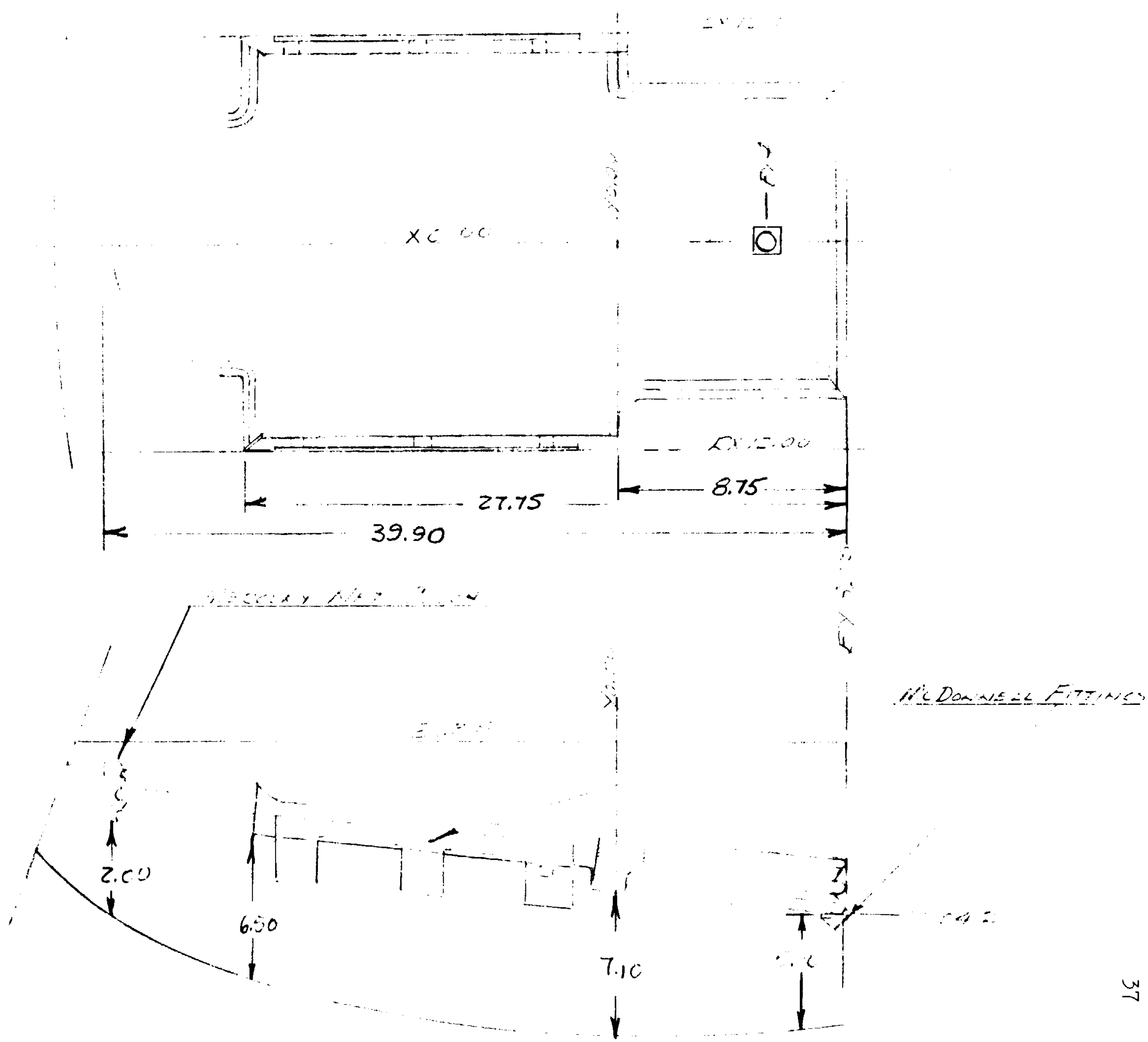



Figure 12.- Space dimensions for net couch in the Mercury spacecraft.

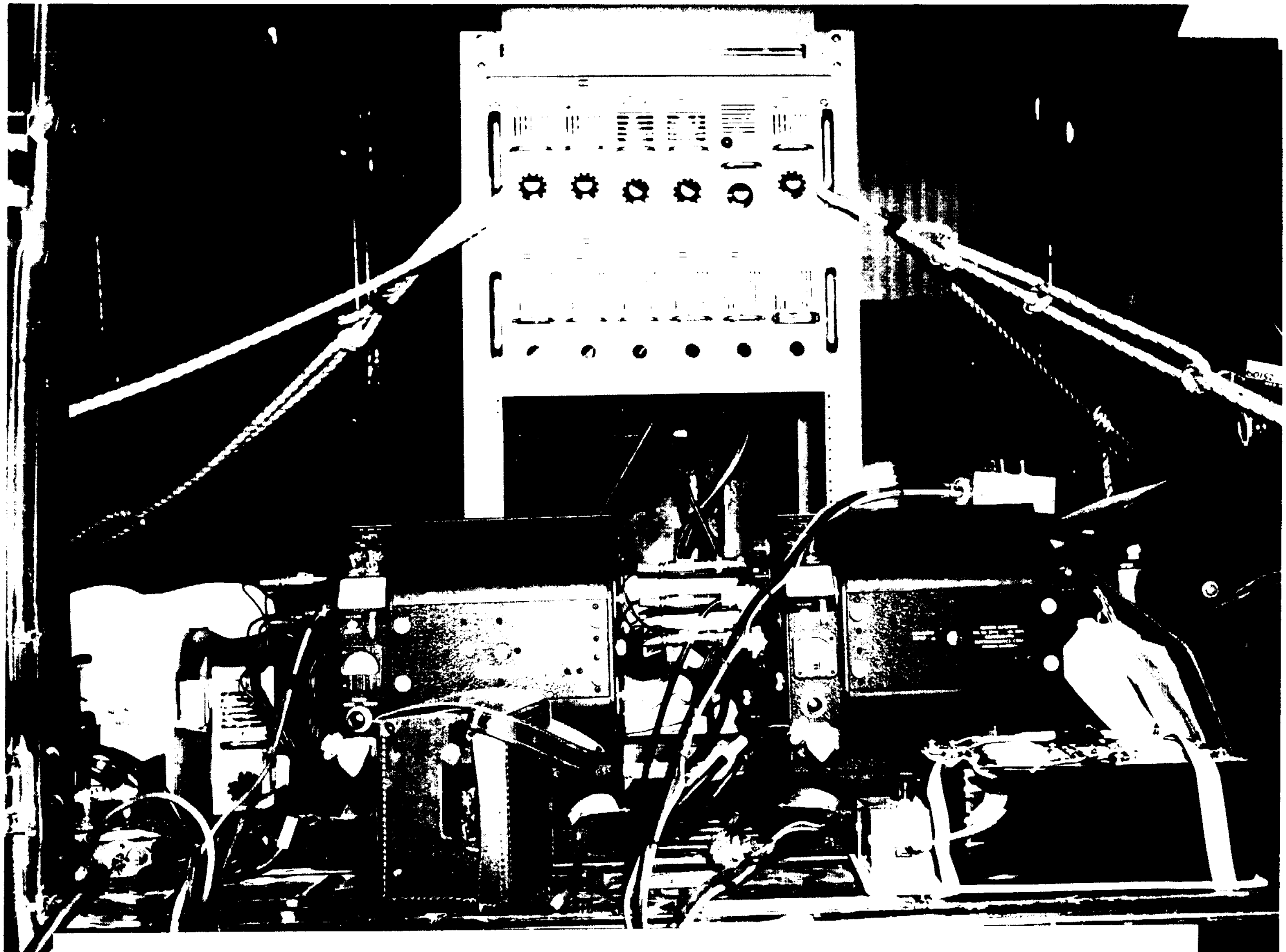


Figure [illegible] .- Instrumentation setup used during spacecraft water drop tests.

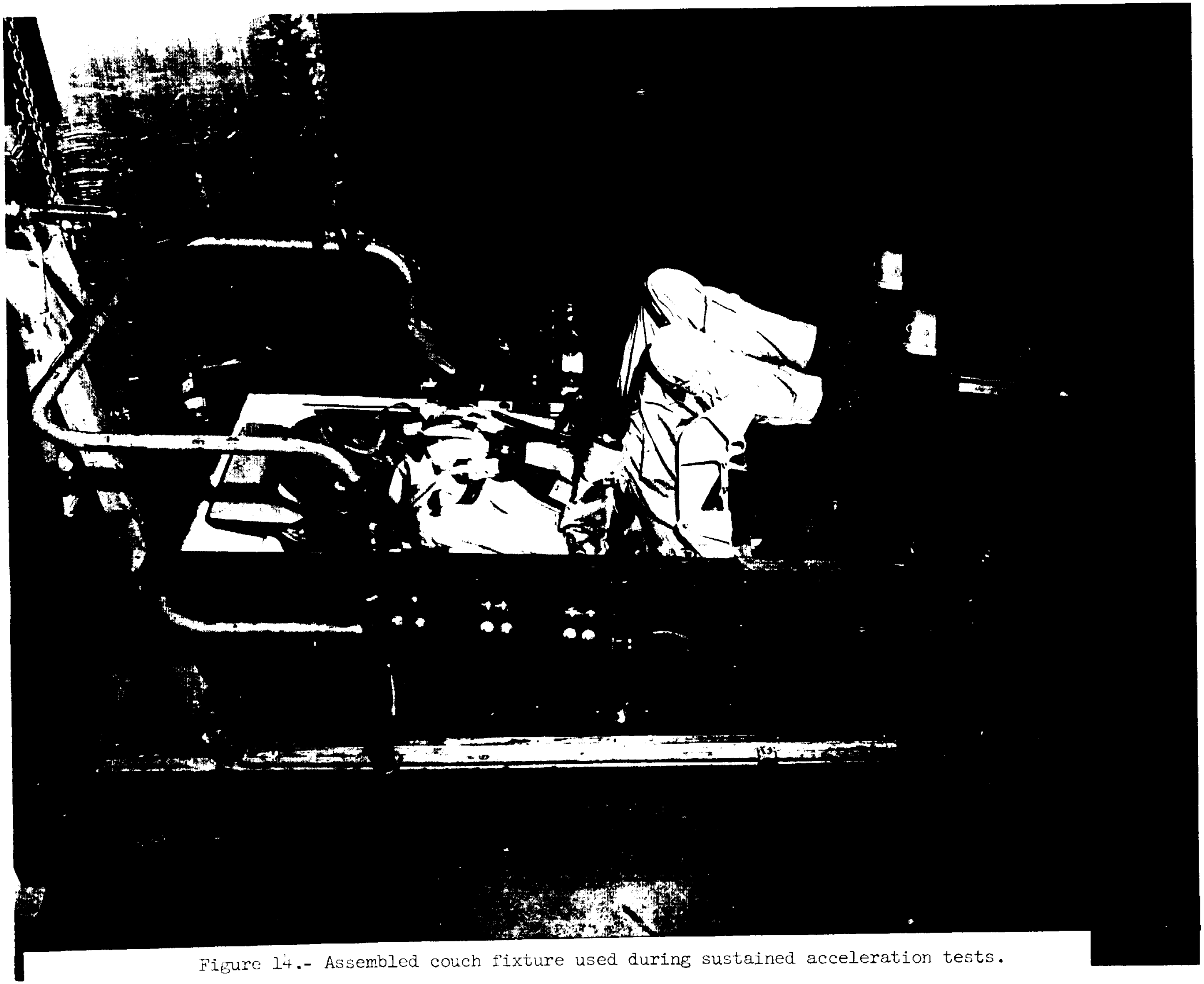


Figure 14.- Assembled couch fixture used during sustained acceleration tests.

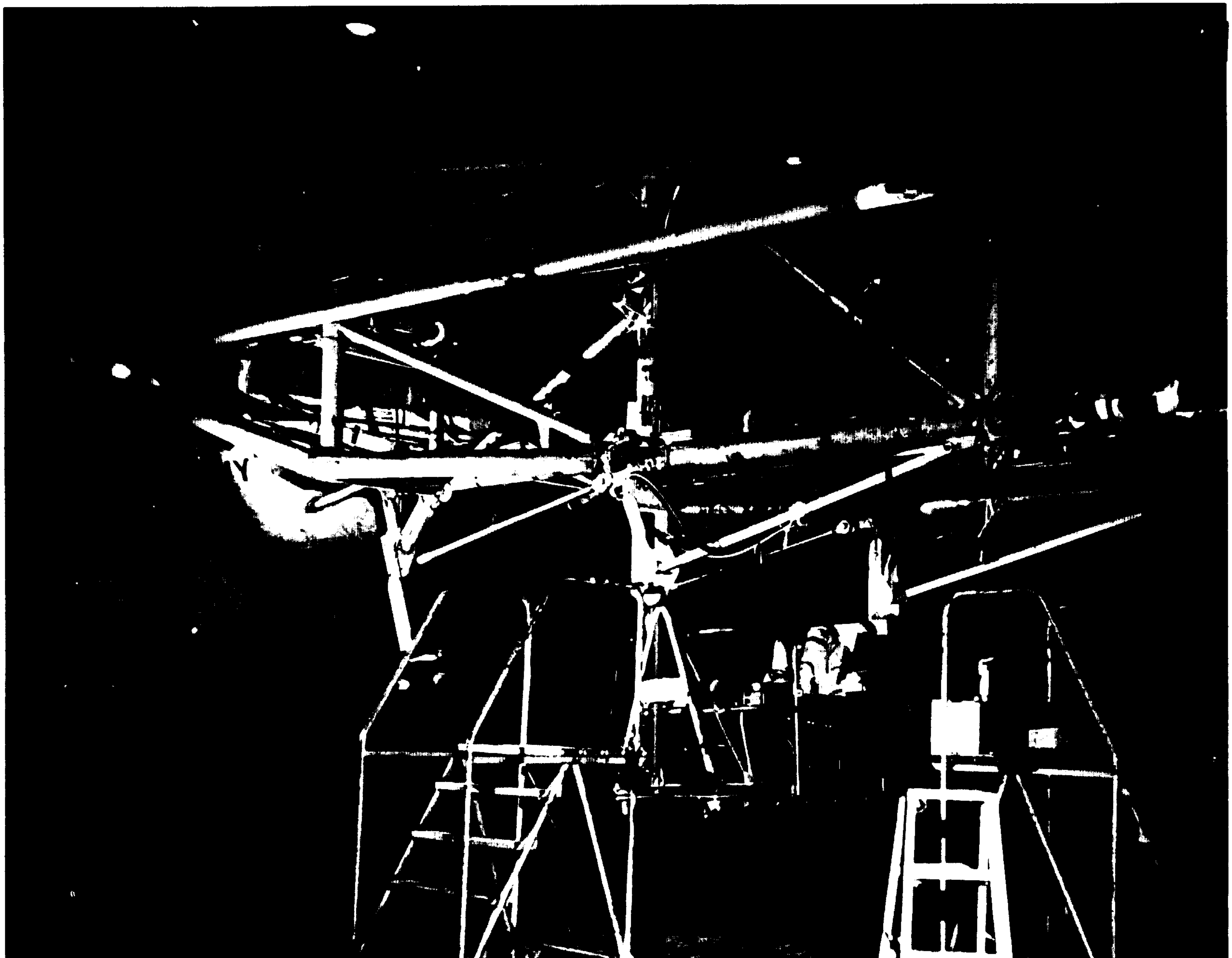


Figure 15.- General test setup during sustained acceleration preloading.

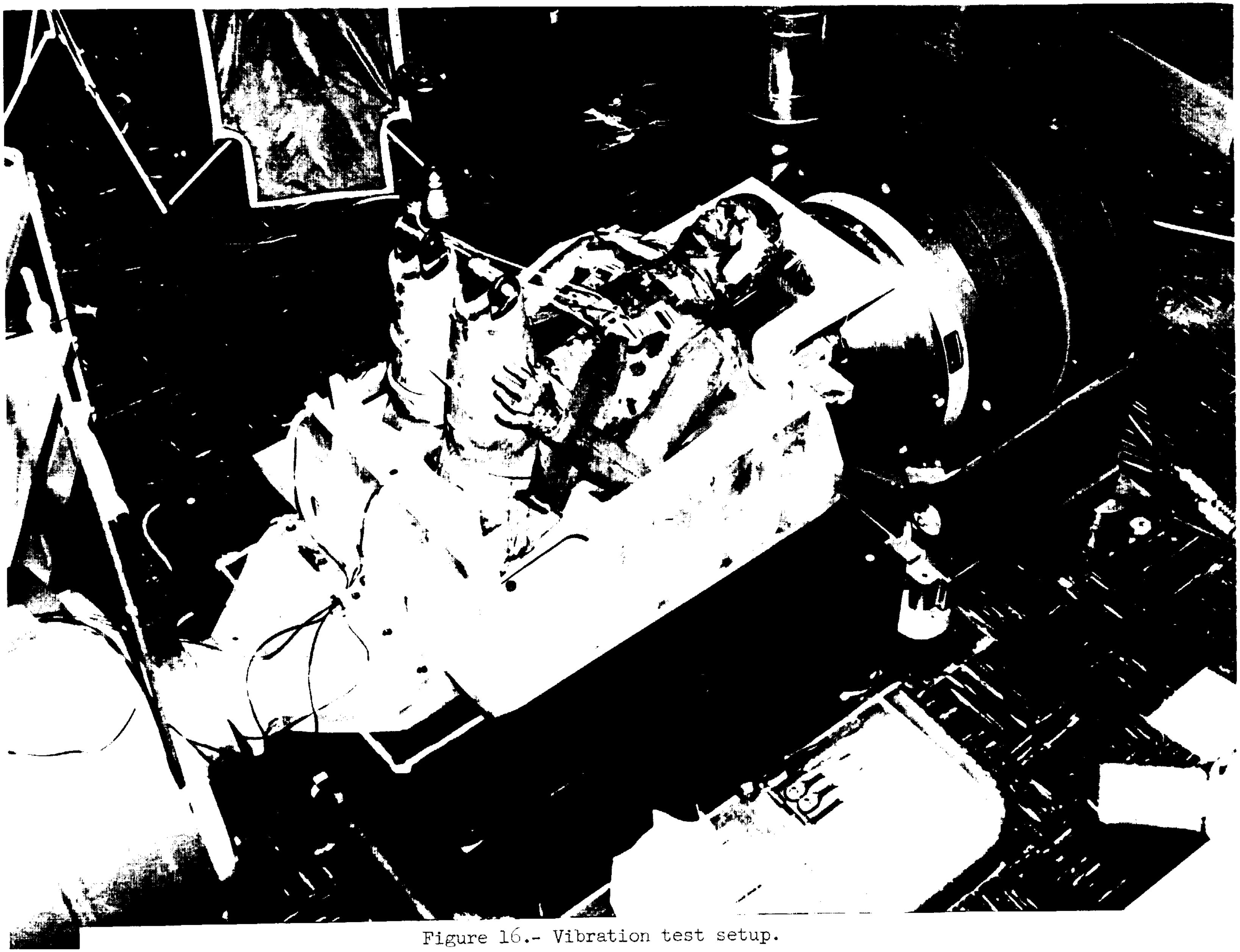


Figure 16.- Vibration test setup.

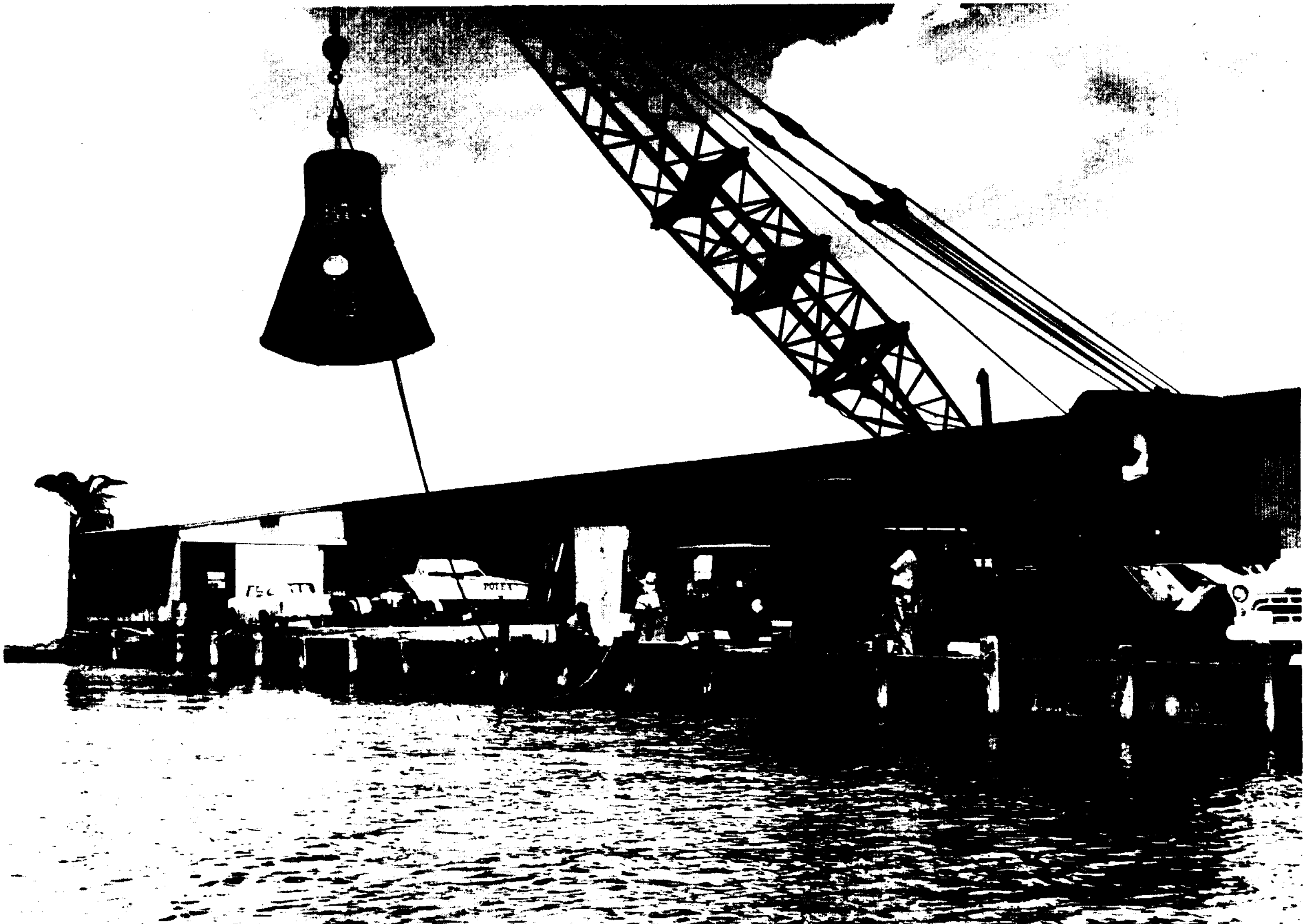


Figure 17.- Spacecraft water drop tests setup.

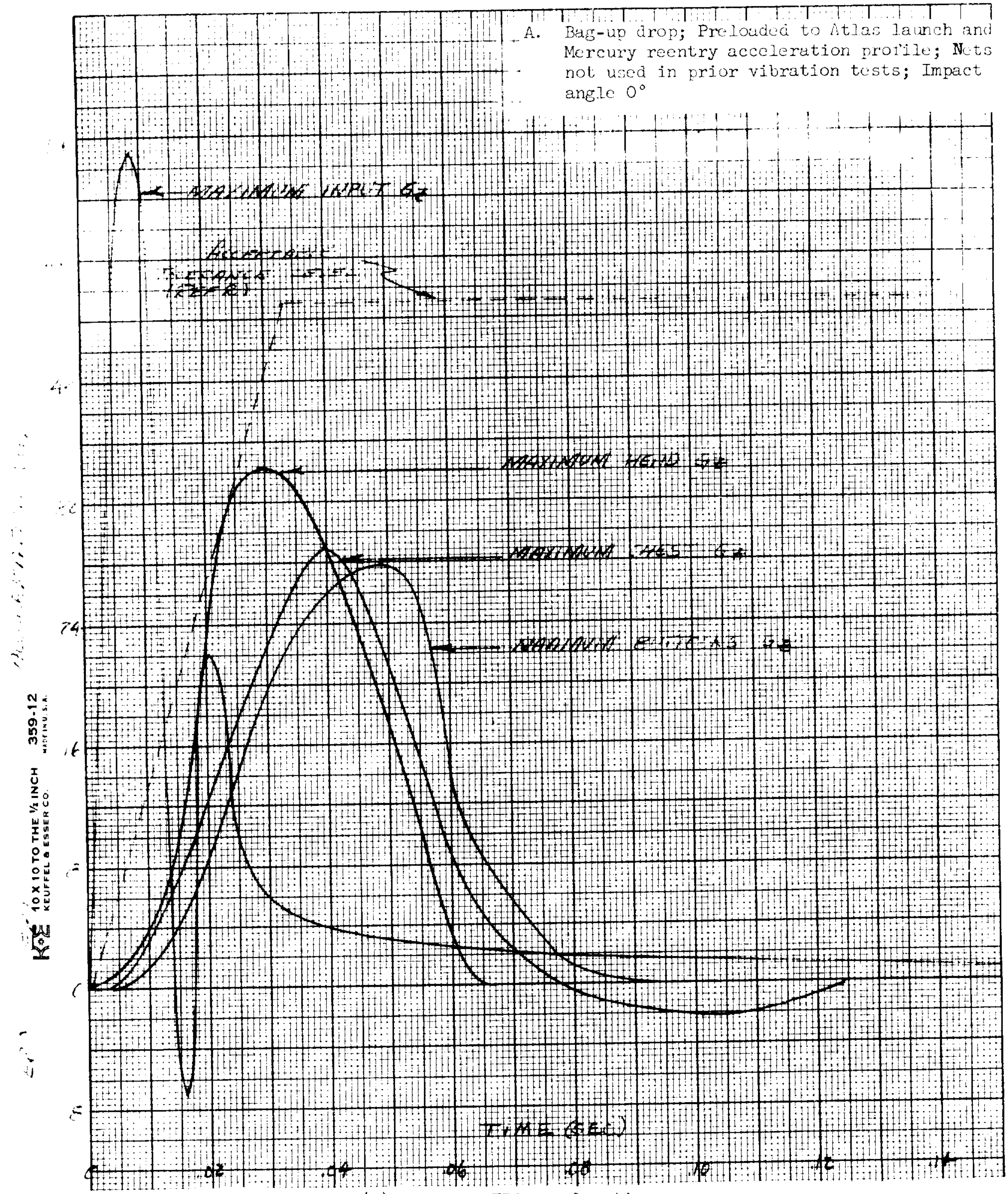

Figure 18.- Couch dummy-assembly inside spacecraft during water-drop tests.

Impact Velocity = 30 feet per second

Spacecraft Weight = 2,450 pounds

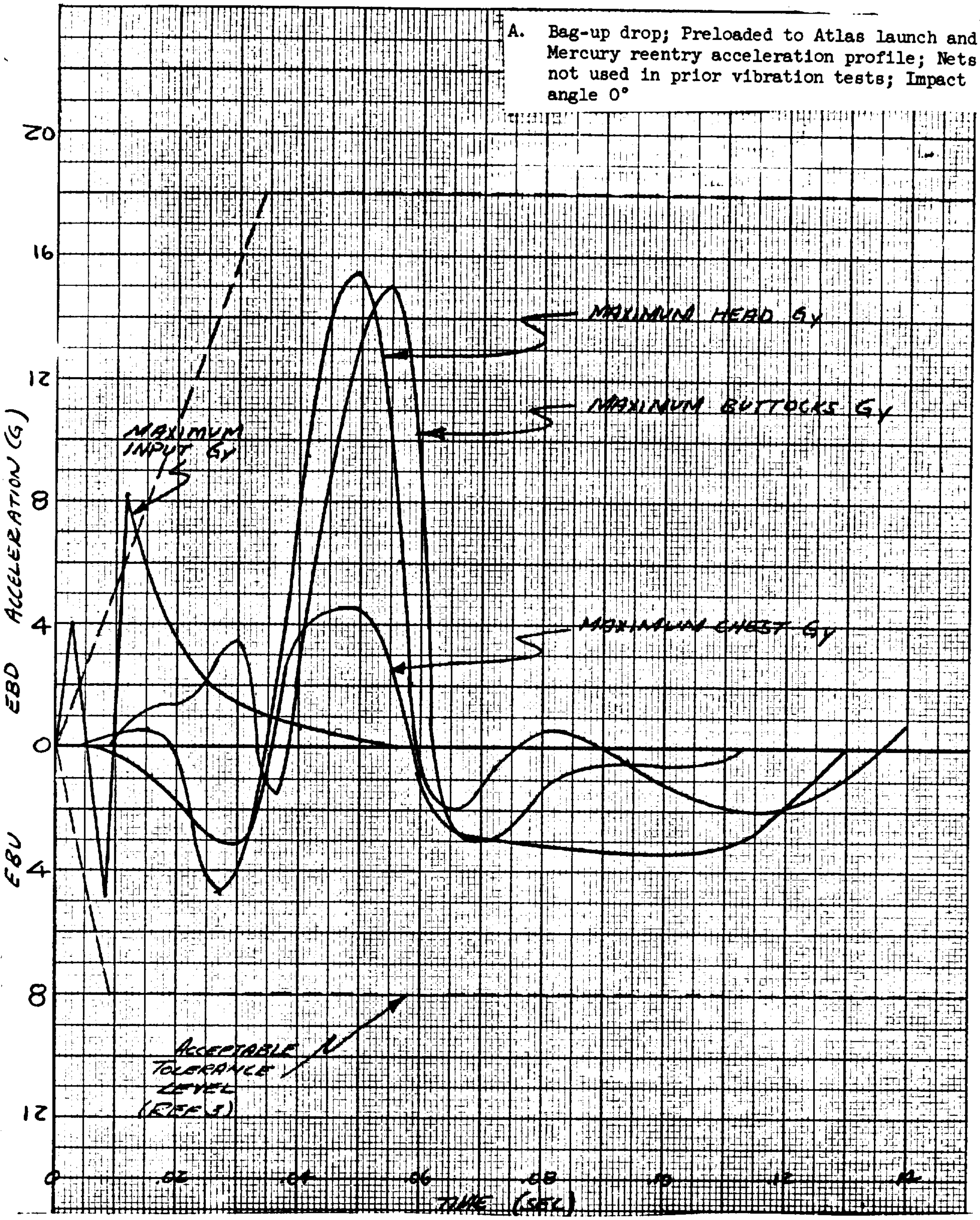
Dummy Weight = 185 pounds

Figure 19.- Net couch qualification test criterion for spacecraft water drops



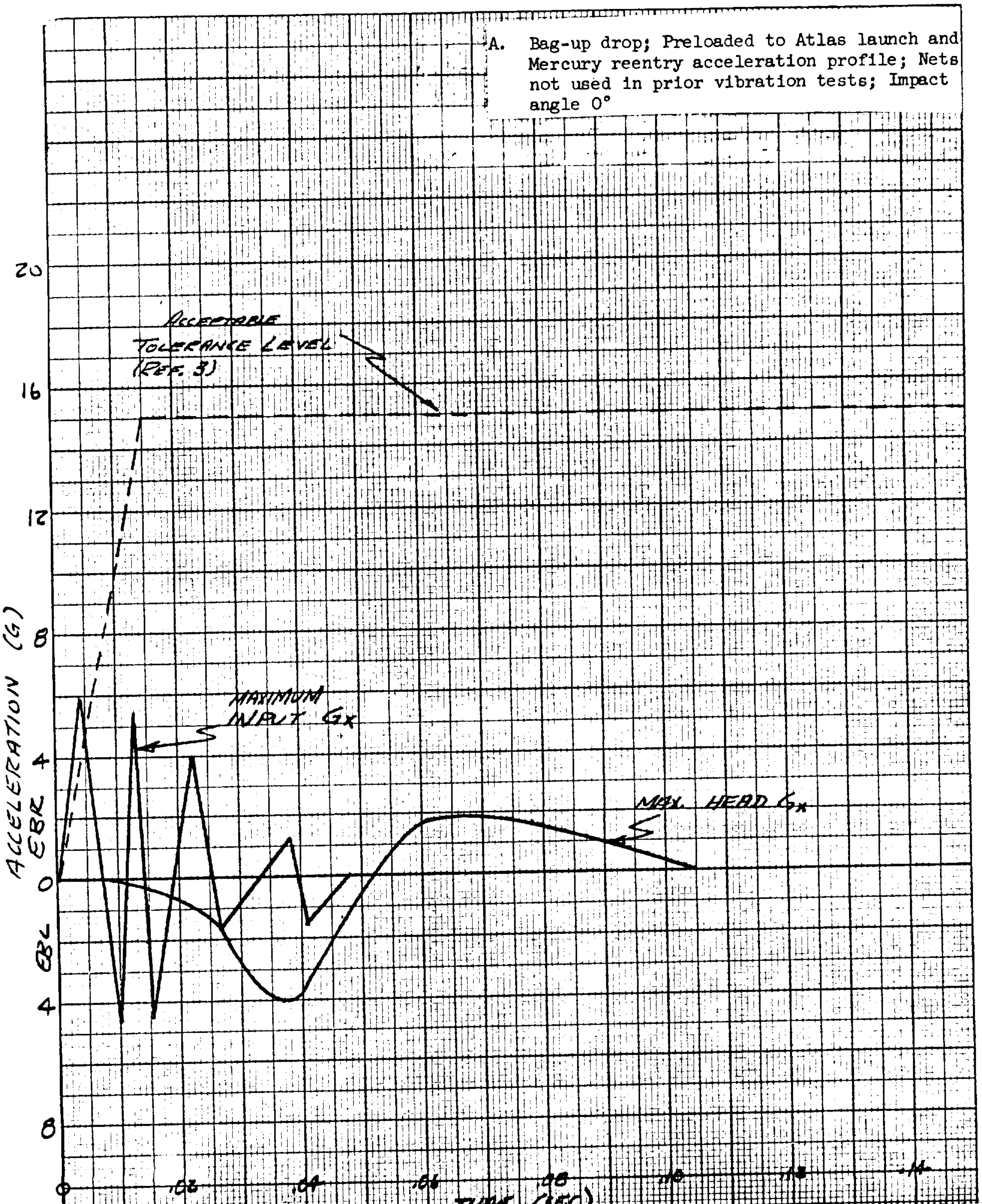

(a) EBI and EBO accelerations.

Figure 20A.- Capsule water drop tests; comparison of spacecraft and couch occupant acceleration-time histories.



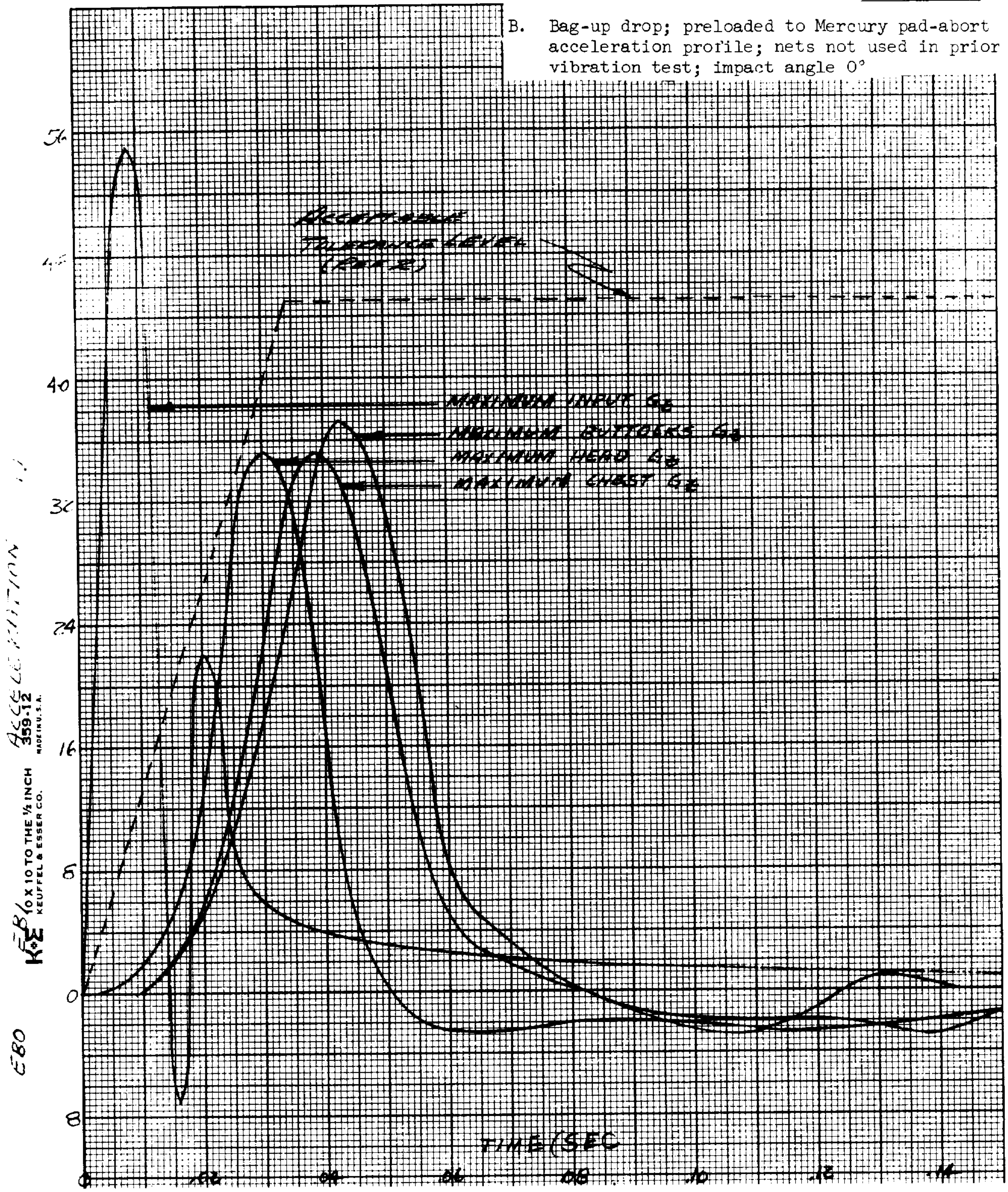

(b) EBU and EBD accelerations.

Figure 20A.- Continued



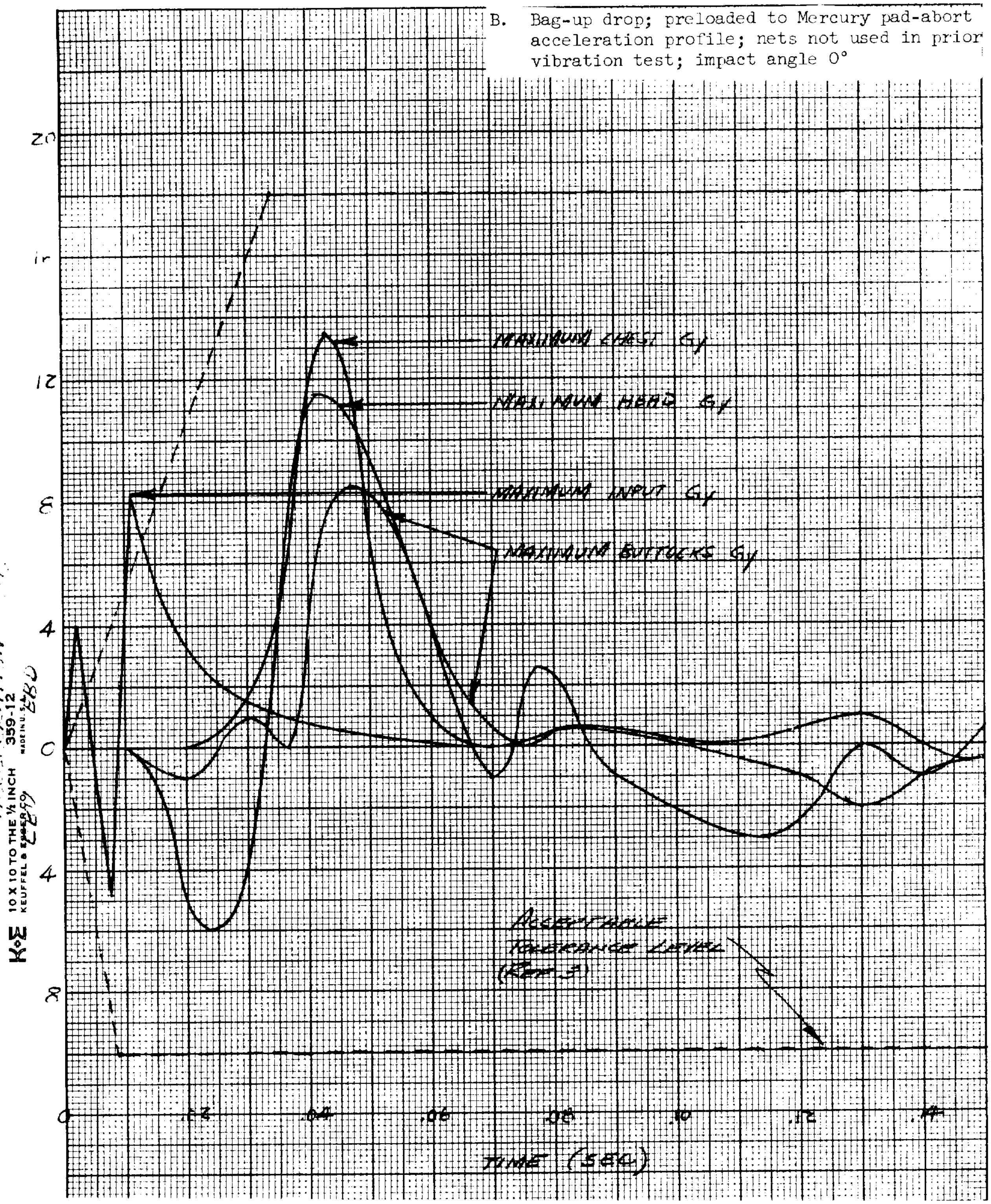

(c) EBR and EBL accelerations.

Figure 20A.- Concluded



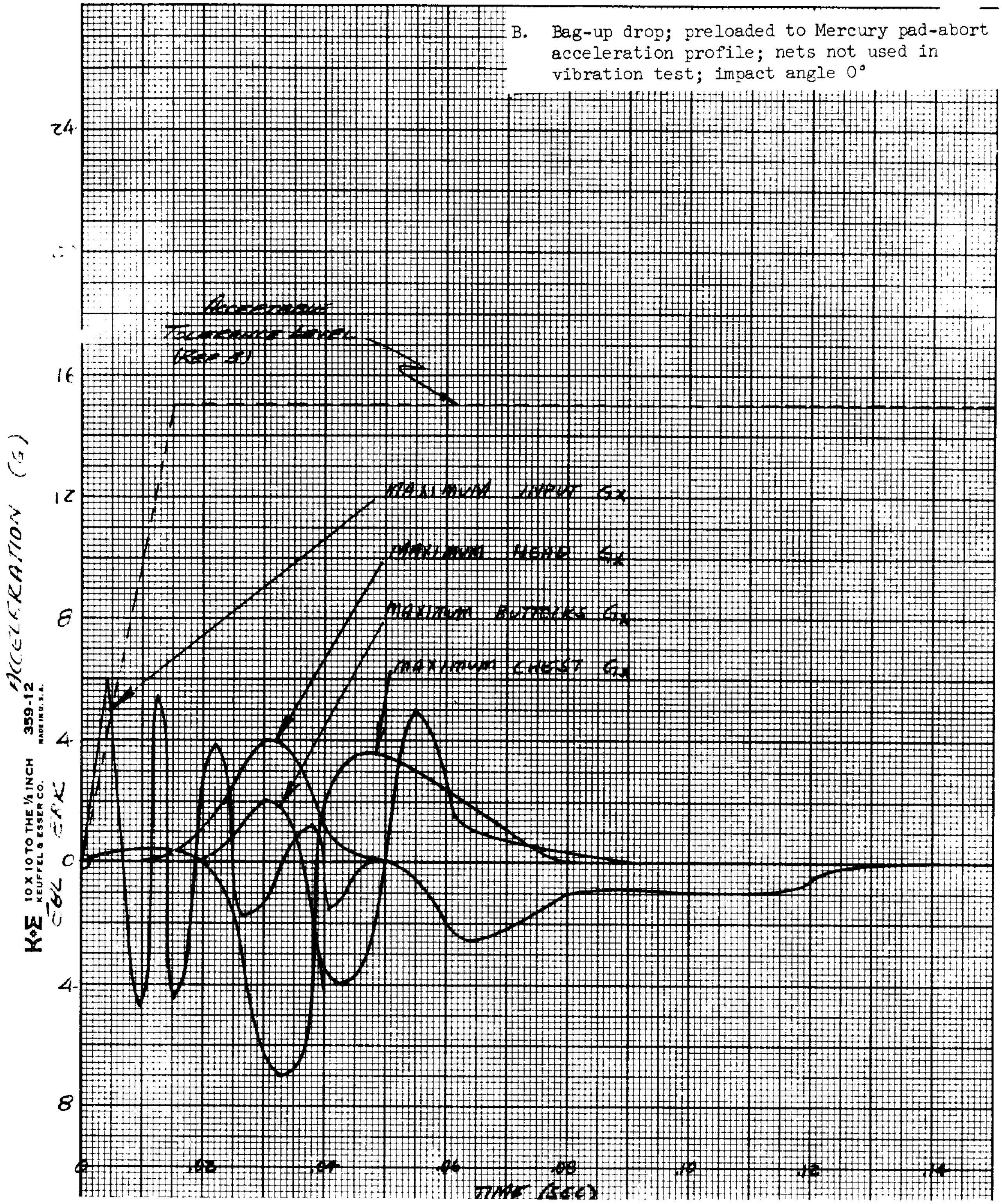

(a) EBI and EBO accelerations.

Figure 20B.- Capsule water drop tests; comparison of spacecraft and couch occupant acceleration-time histories.




(b) EBU and EBD accelerations.

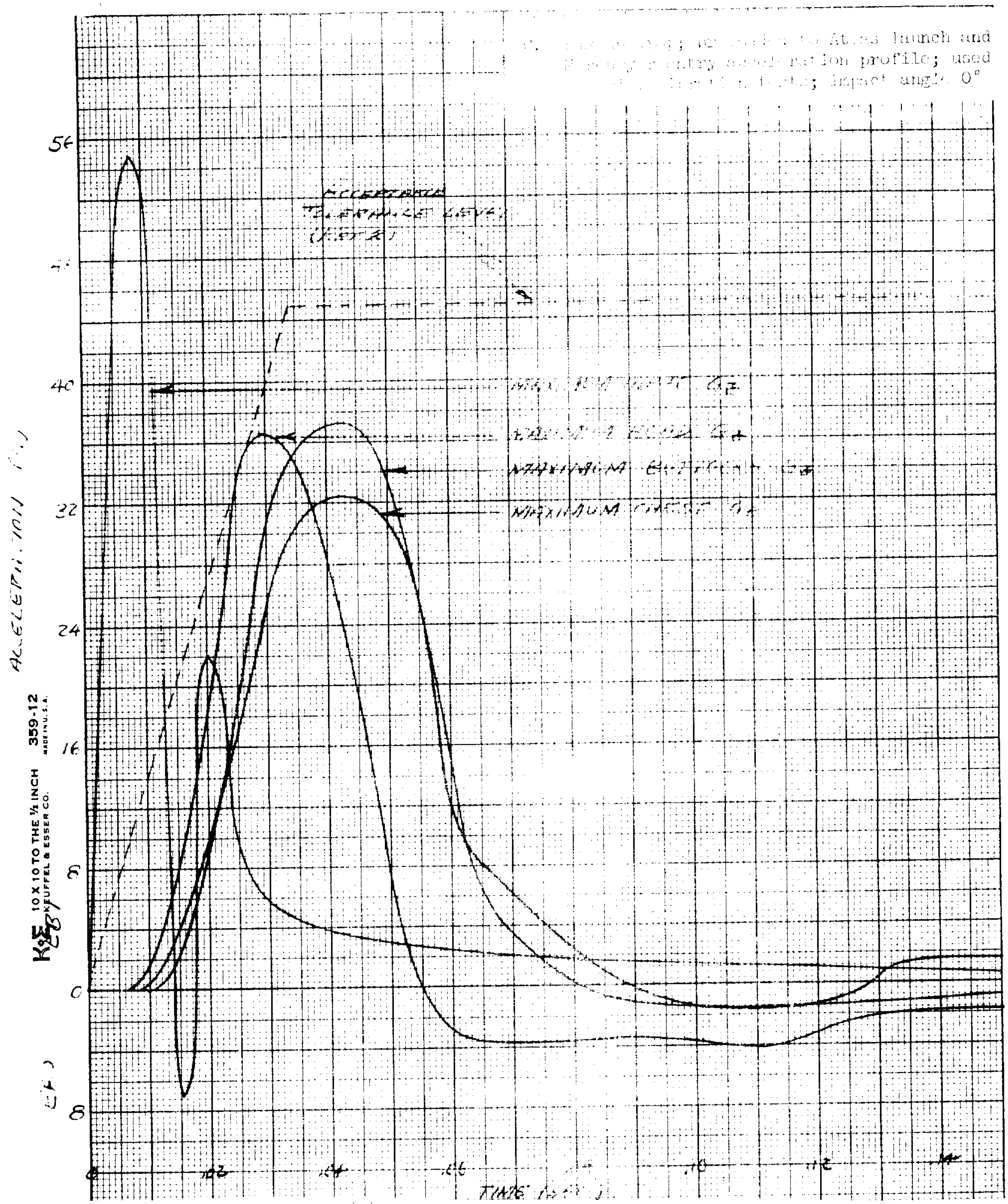
Figure 20B.- Continued




(c) EBR and EBL accelerations.

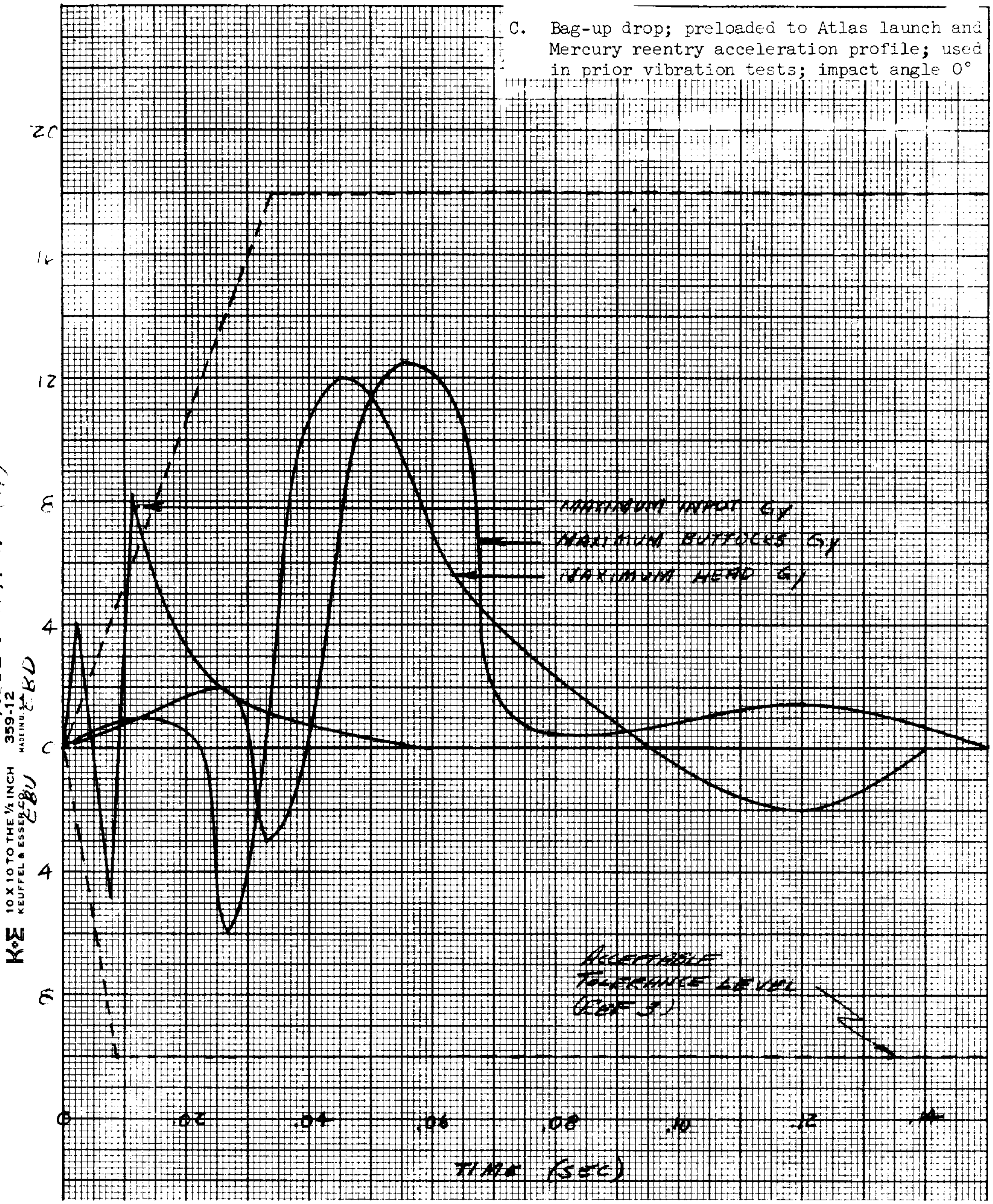
Figure 20B.- Concluded

[illegible]; [illegible] Atlas launch and [illegible] entry [illegible] ration profile; used [illegible]; impact angle 0°



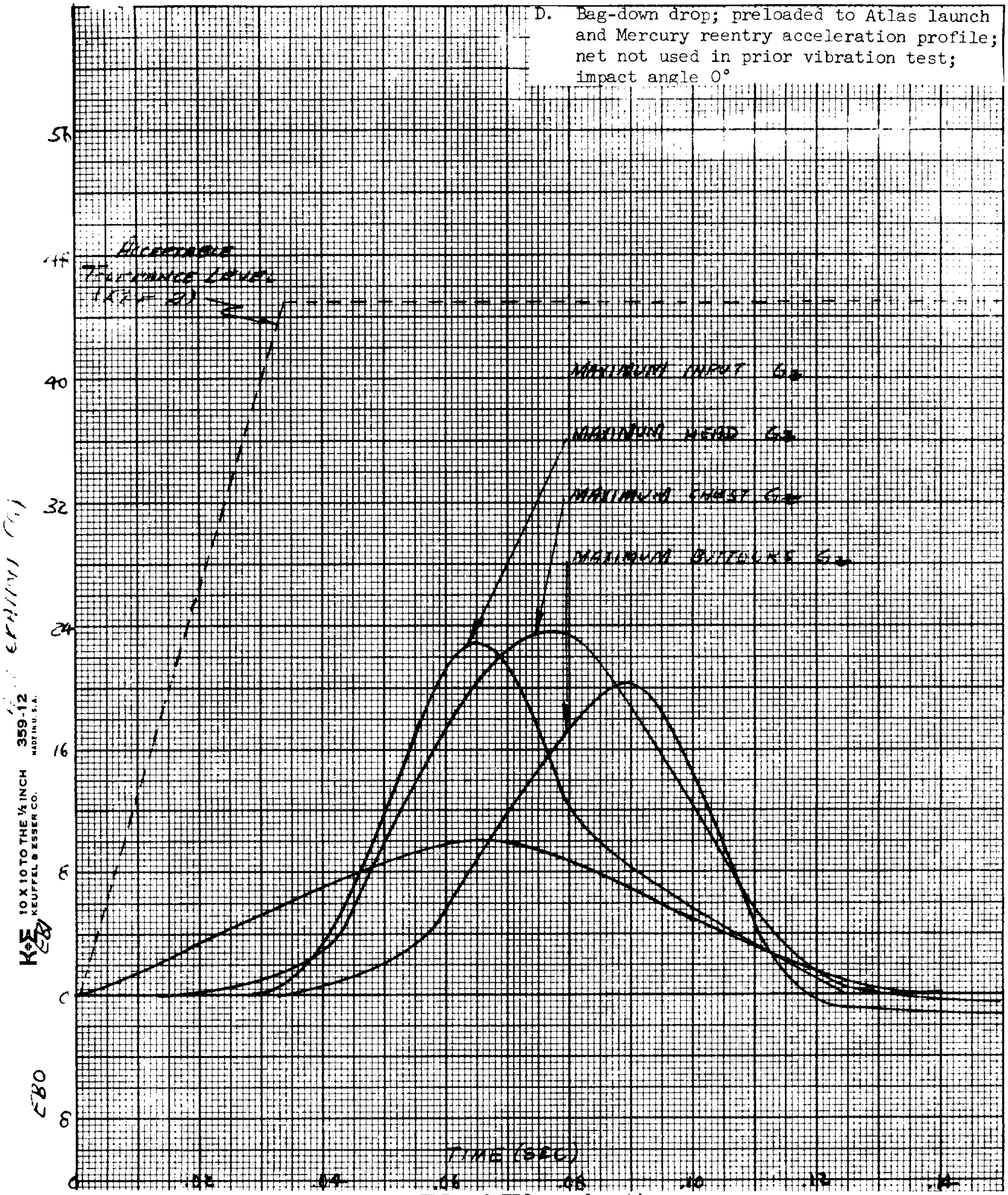

(a) [illegible]

Figure 20C.- Capsule water drop t[illegible]; [illegible] of [illegible] and couch occupant [illegible] histories.



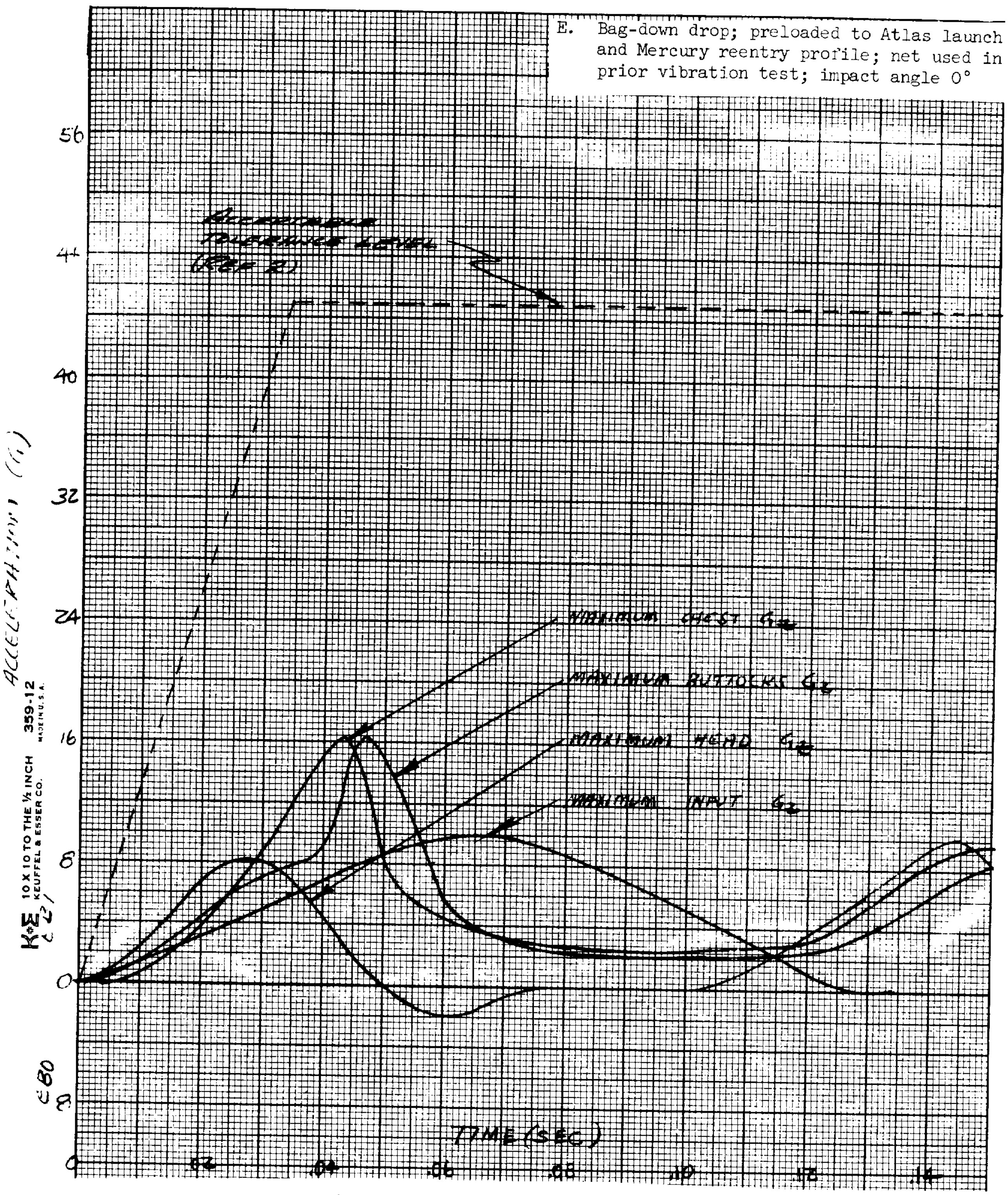

(b) EBU and EBD accelerations.

Figure 20C.- Concluded



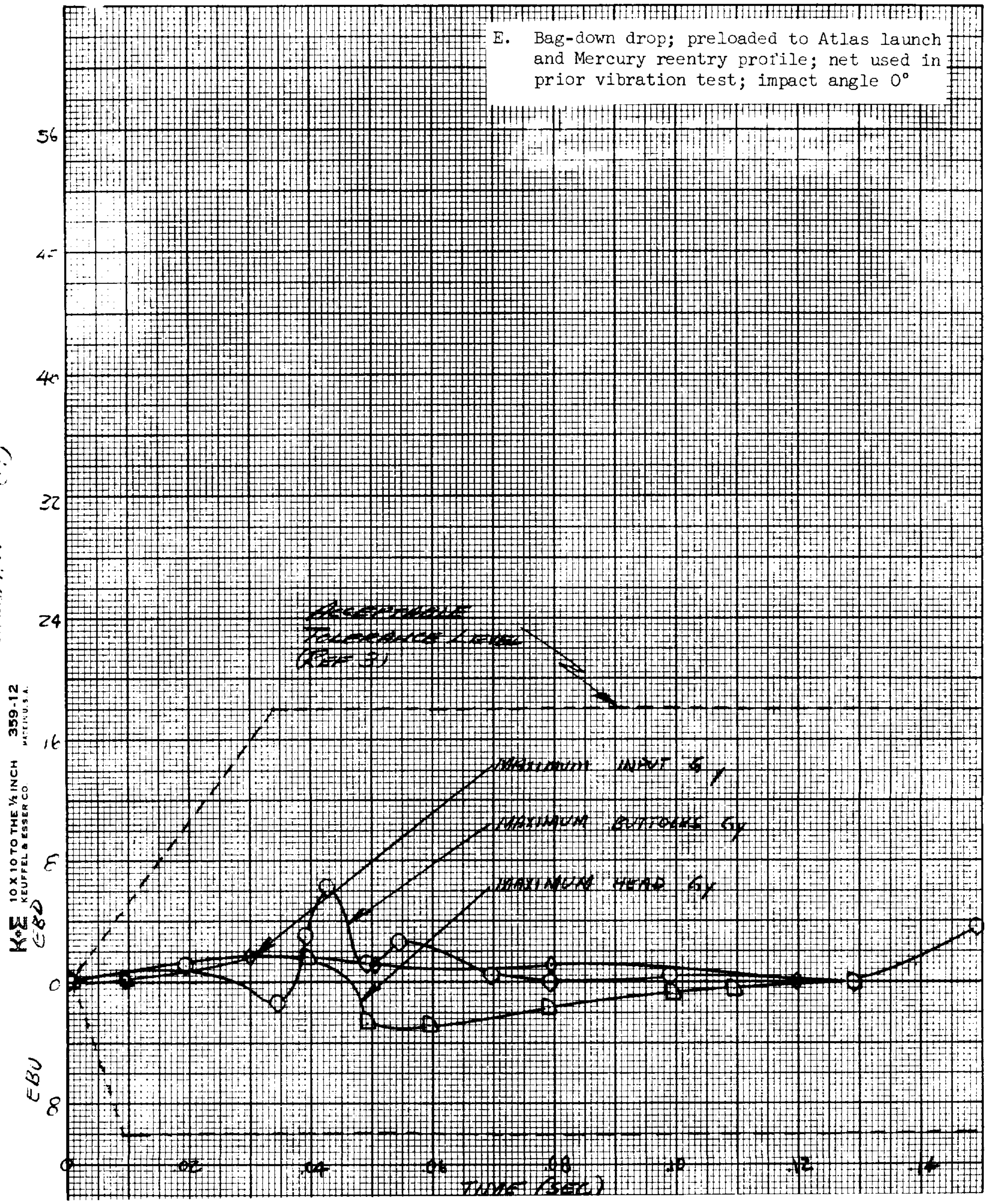

EBI and EBO accelerations

Figure 20D.- Capsule water drop tests; comparison of spacecraft and couch occupant acceleration-time histories.



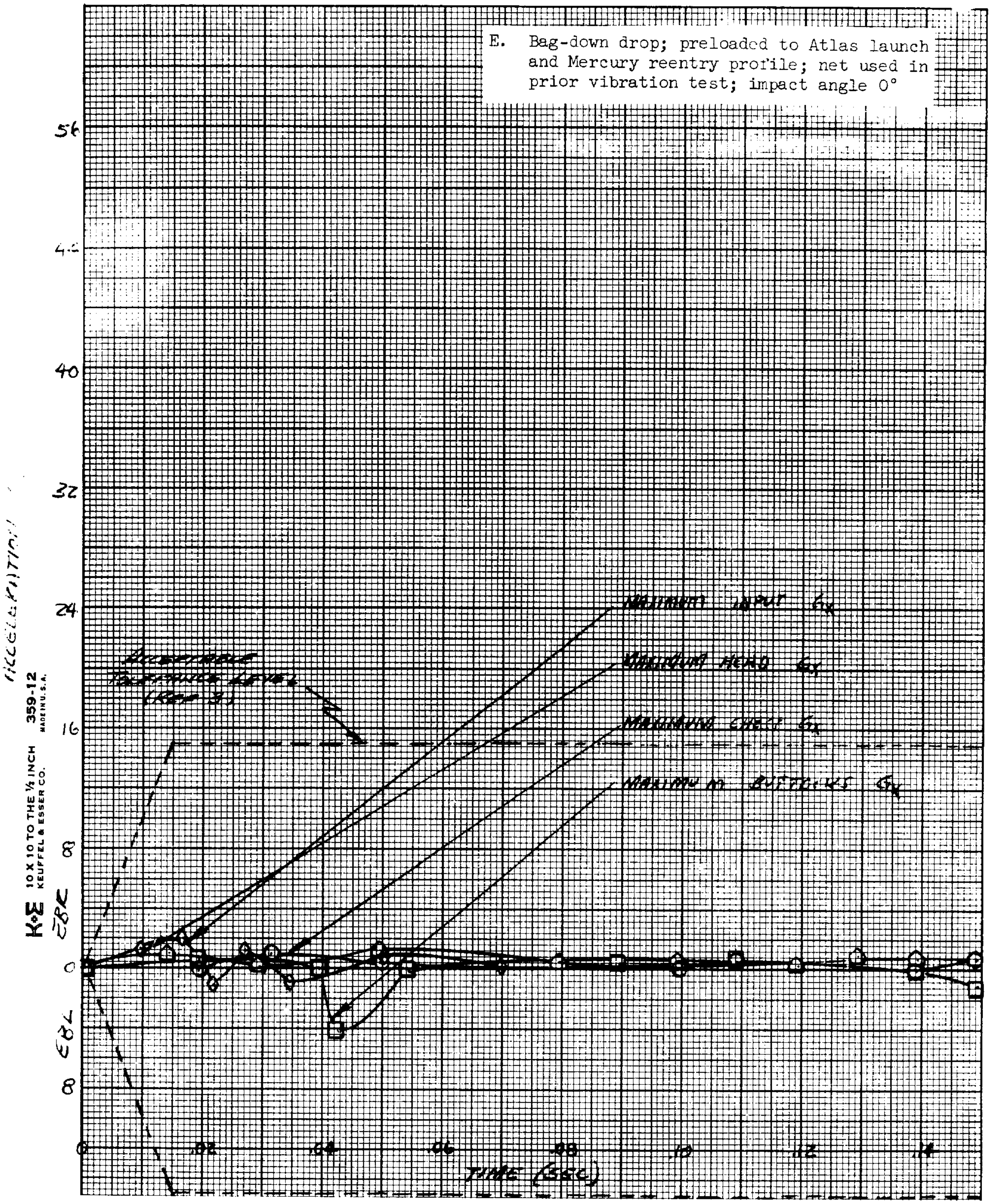

(a) EBI and EBO accelerations.

Figure 20E.- Capsule water drop tests; comparison of spacecraft and couch occupant acceleration-time histories.



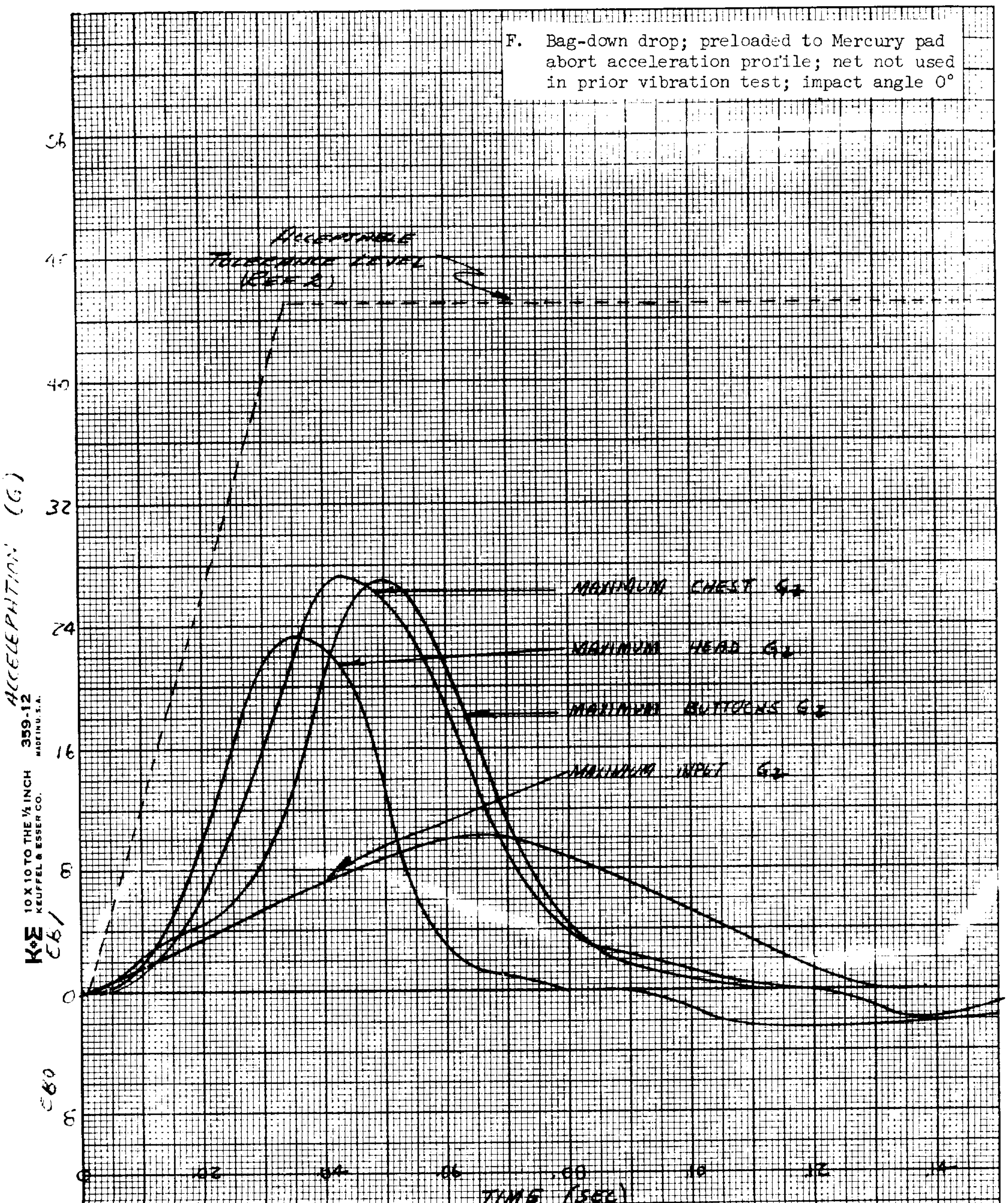

(b) EBU and EBD accelerations.

Figure 20E.- Continued



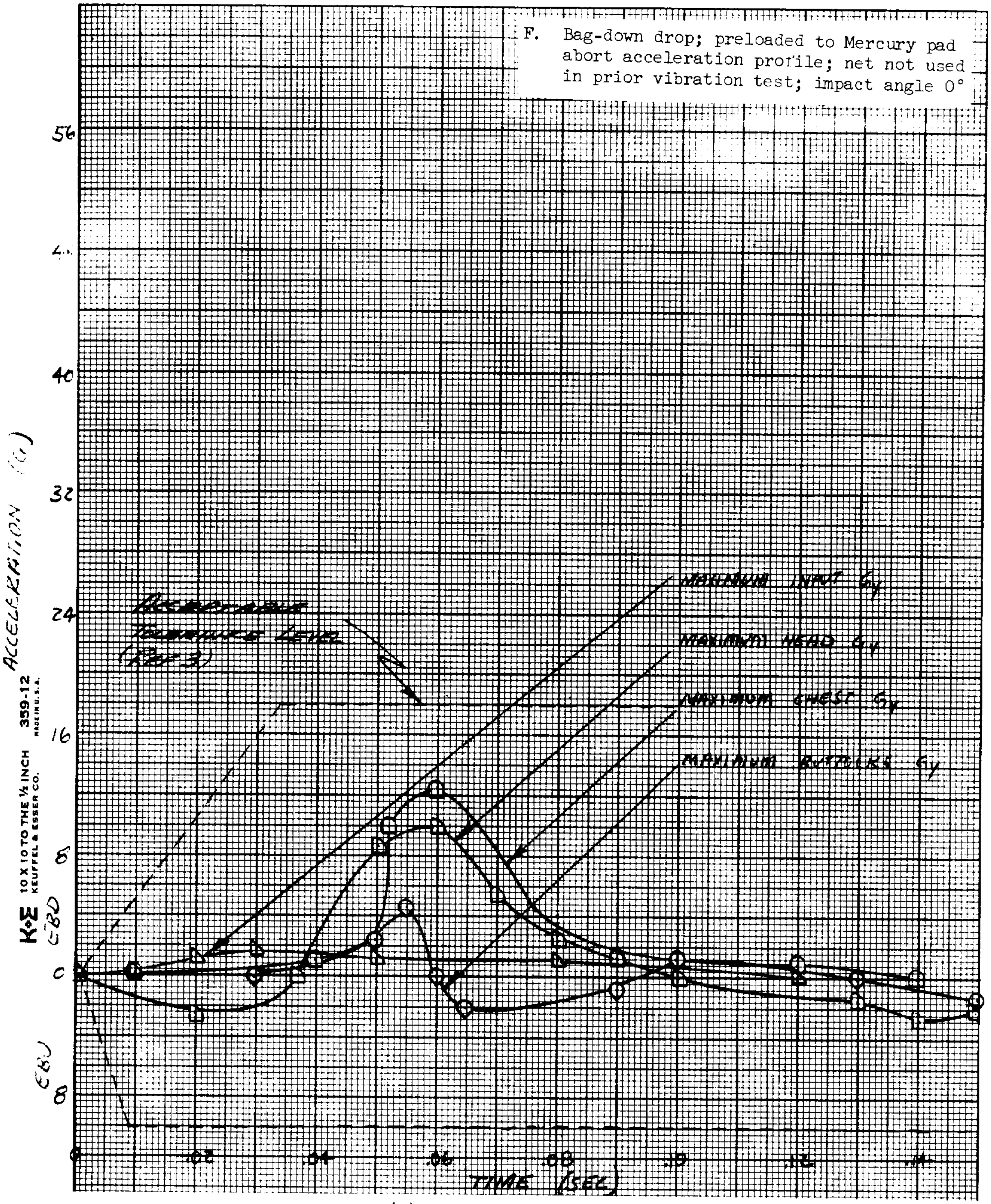

(c) EBR and EBL accelerations.

Figure 20E.- Concluded



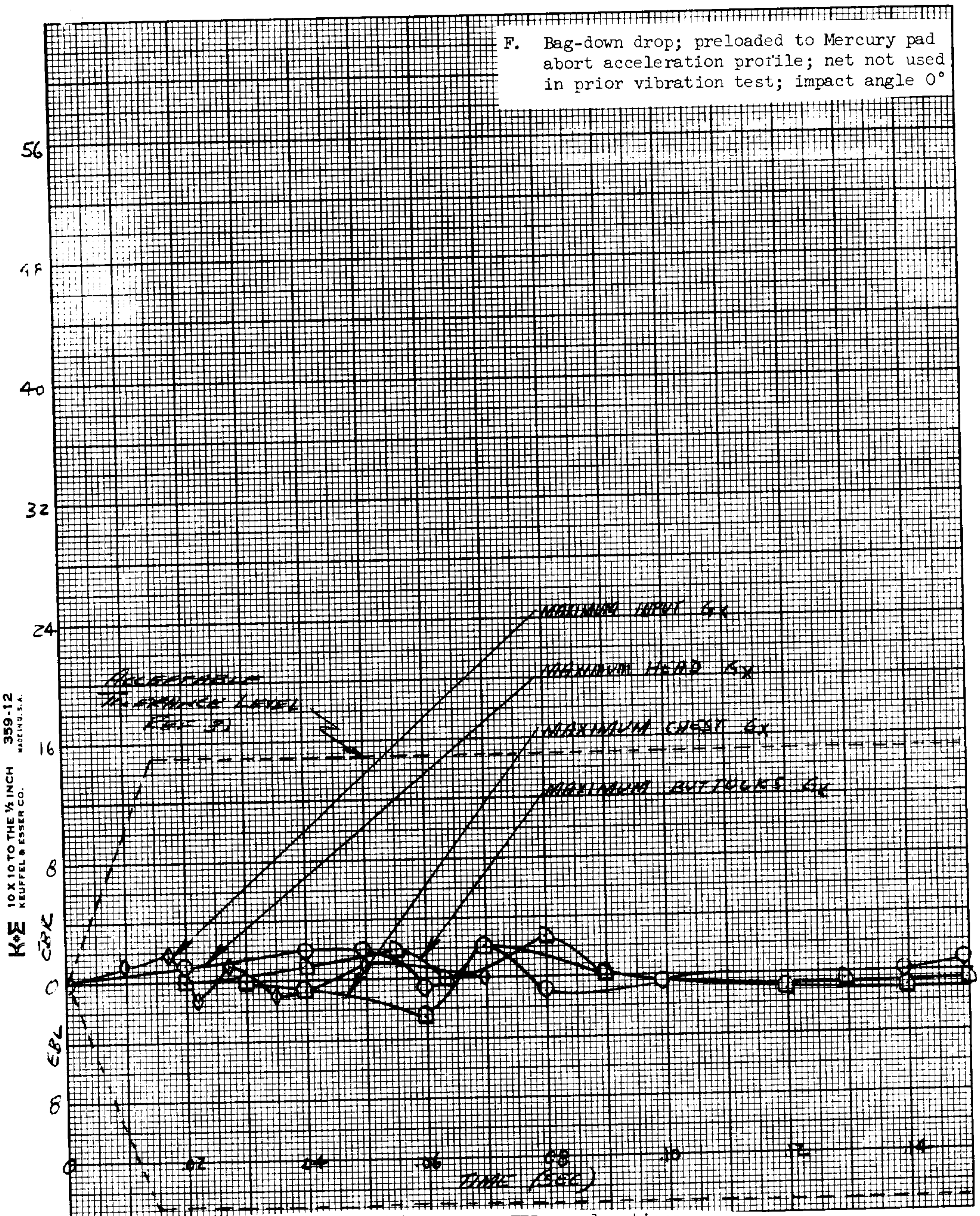

(a) EBI and EBO accelerations.

Figure 20F.- Capsule water drop tests; comparison of spacecraft and couch occupant acceleration-time histories.



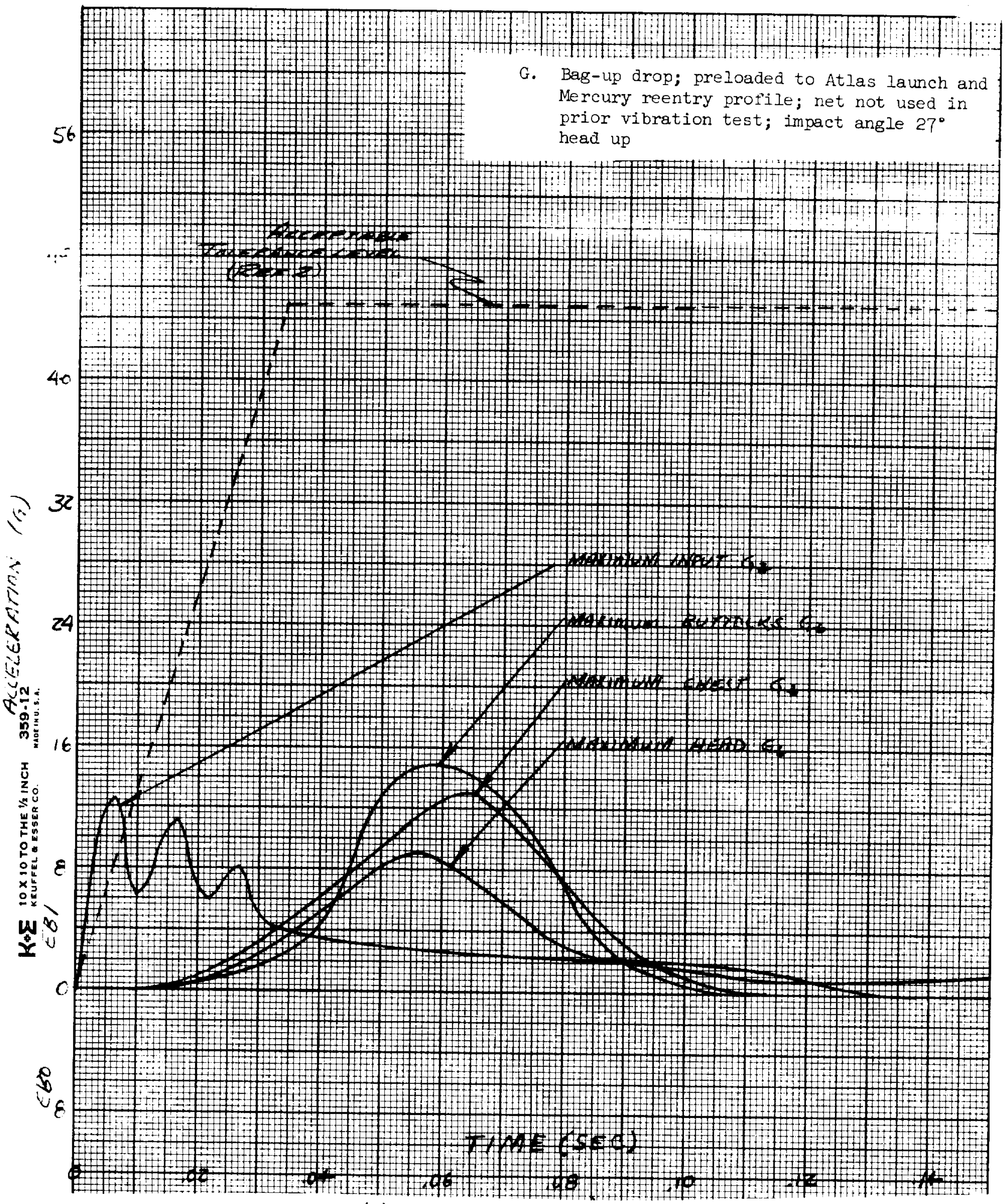

(b) EBU and EBD accelerations.

Figure 20F.- Continued



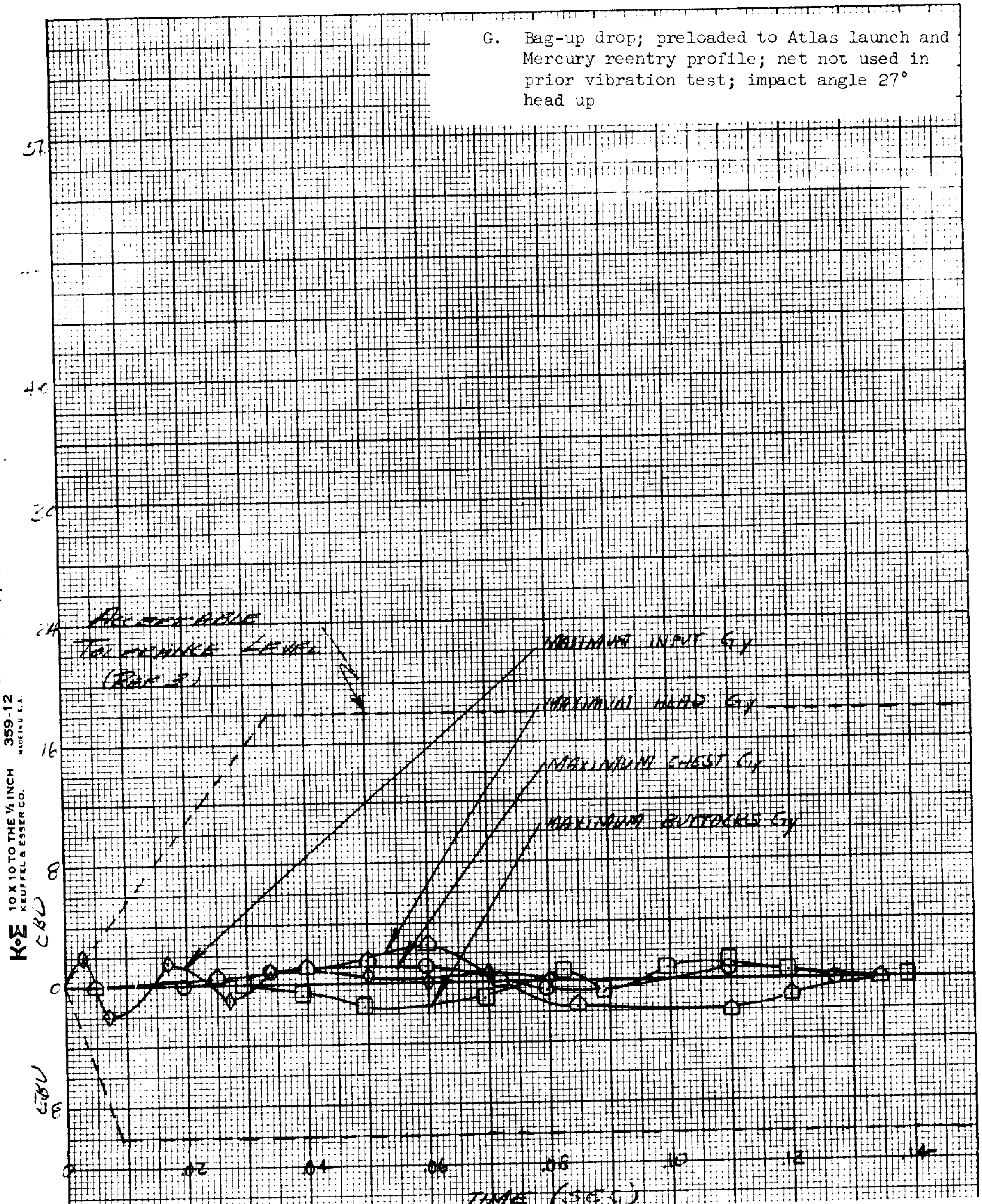

(c) EBR and EBL accelerations.

Figure 20F.- Concluded



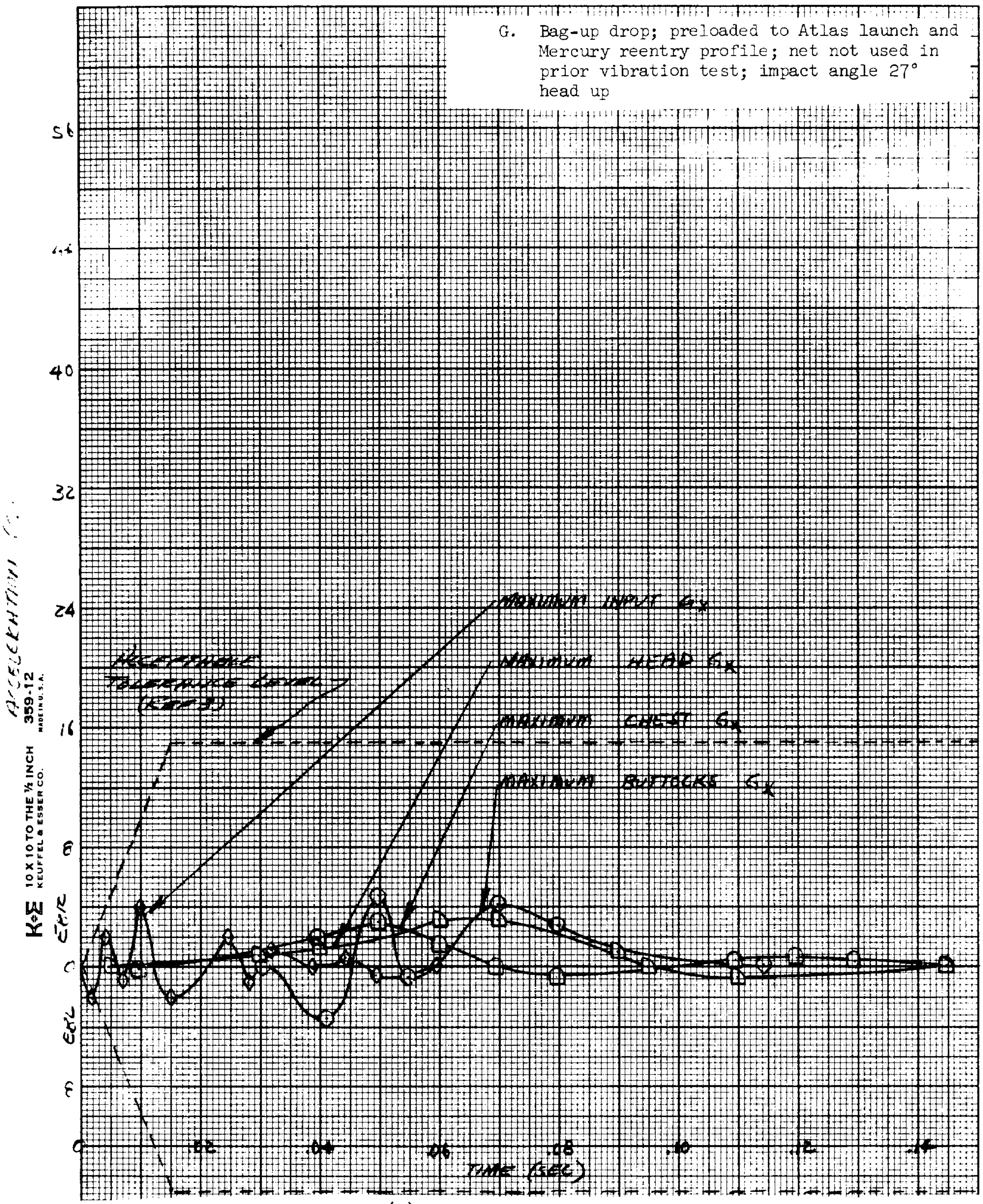

(a) EBI and EBO accelerations.

Figure 20G.- Capsule water drop tests; comparison of spacecraft and couch occupant acceleration-time histories.



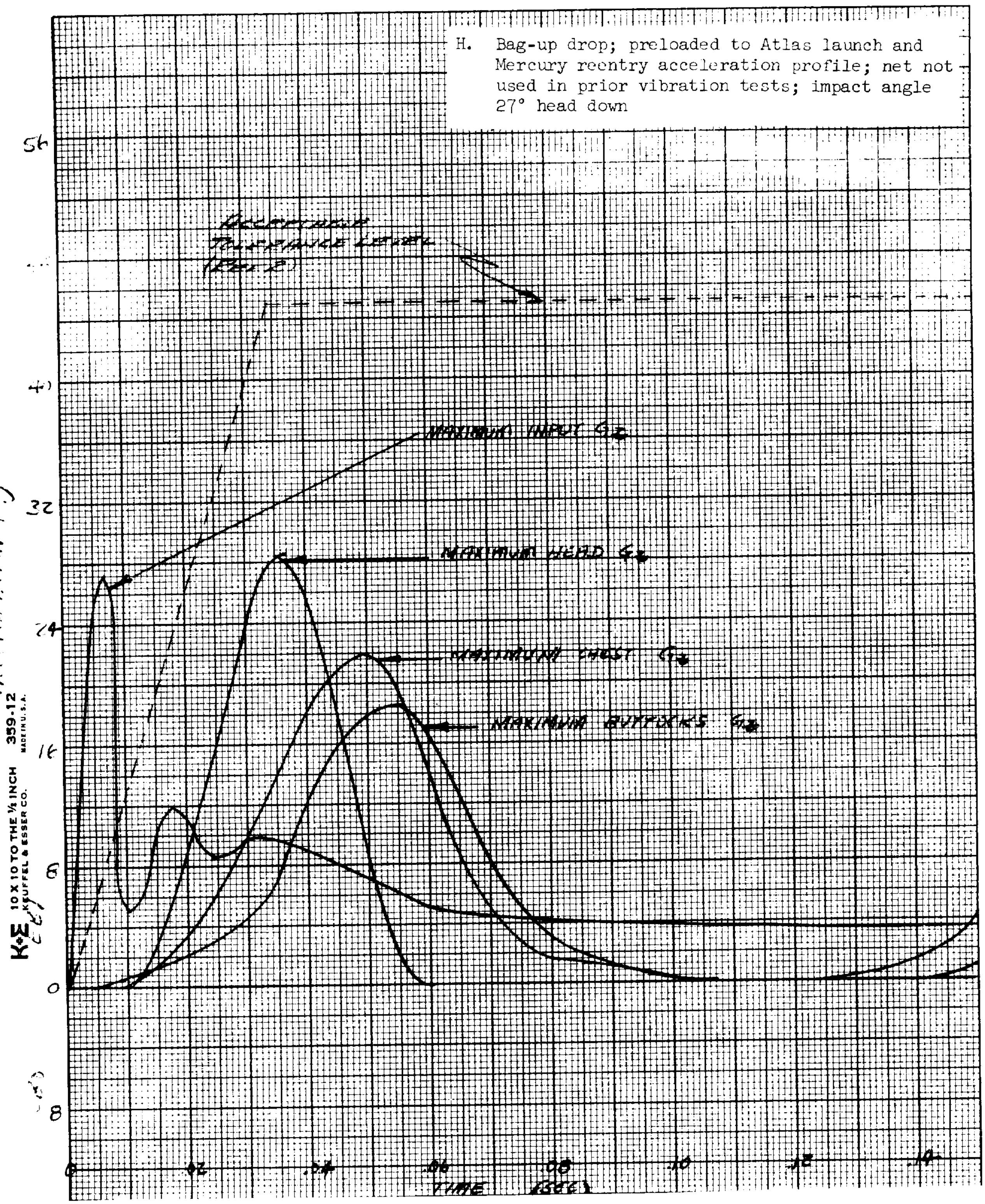

(b) EBU and EBD accelerations.

Figure 20G.- Continued



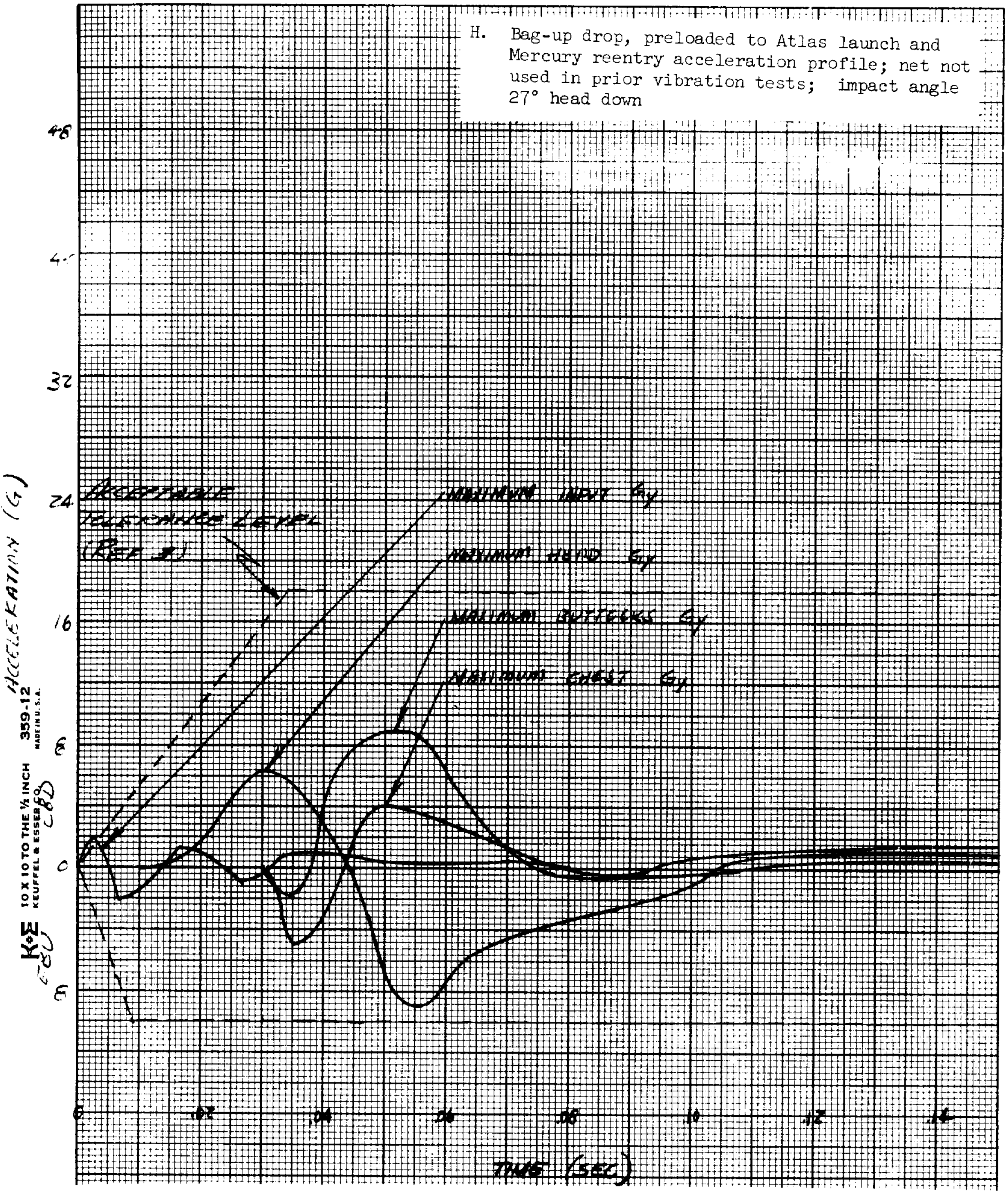

(c) EBR and EBL accelerations.

Figure 20G.- Concluded



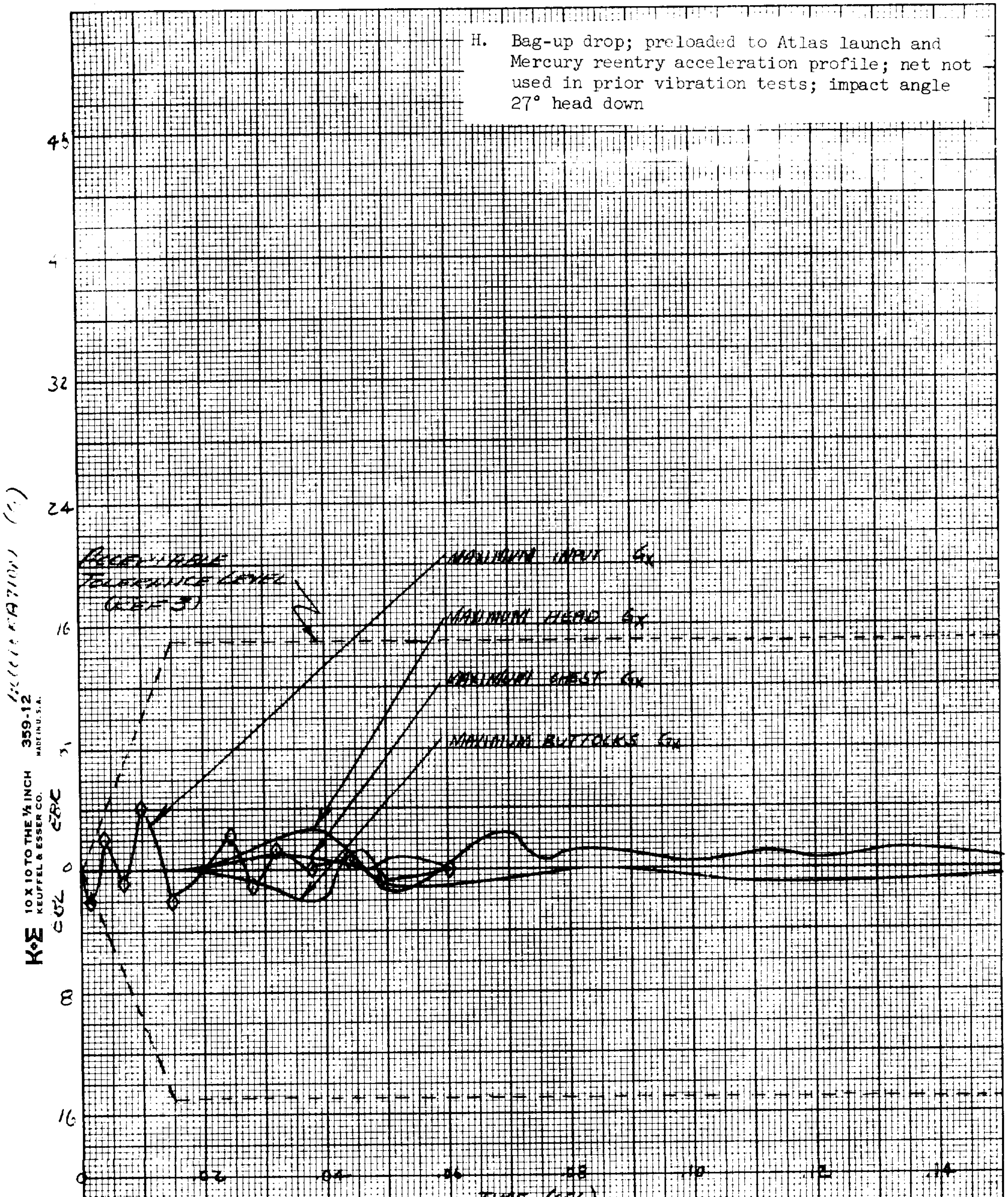

(a) EBI and EBO accelerations.

Figure 20H.- Capsule water drop tests; comparison of spacecraft and couch occupant acceleration-time histories.



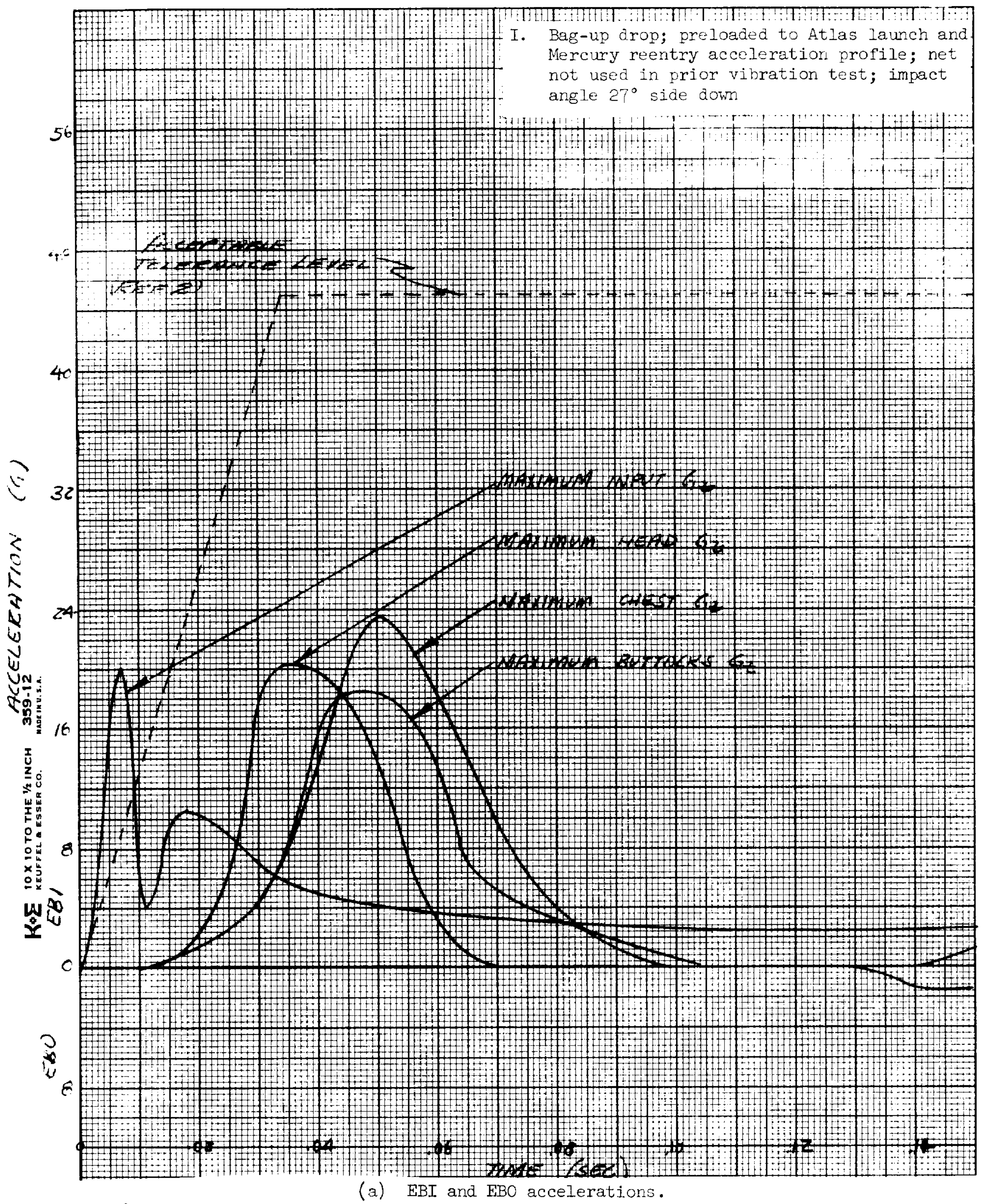

(b) EBU and EBD accelerations.

Figure 20H.- Continued



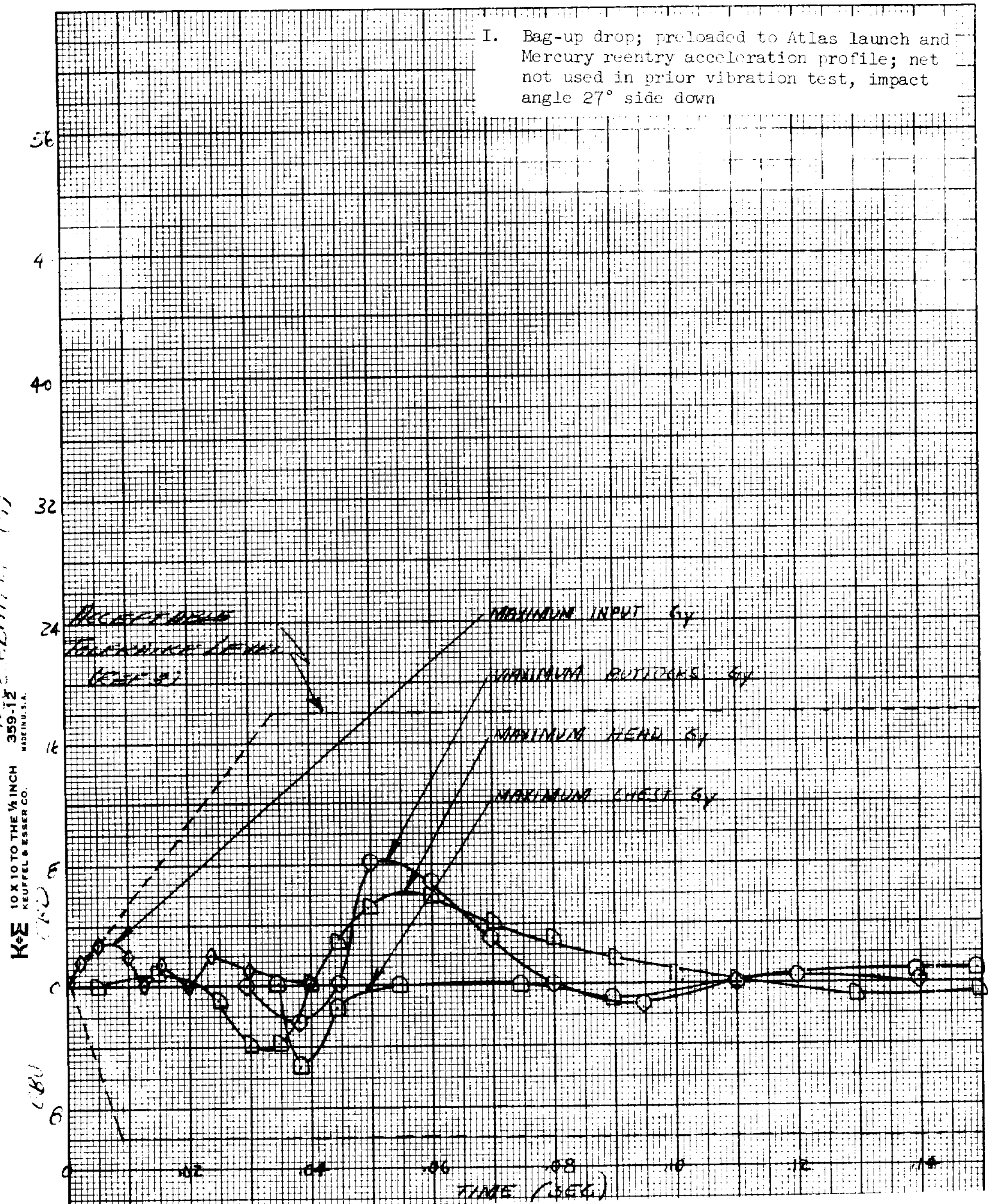

(c) EBR and EBL accelerations.

Figure 20H.- Concluded



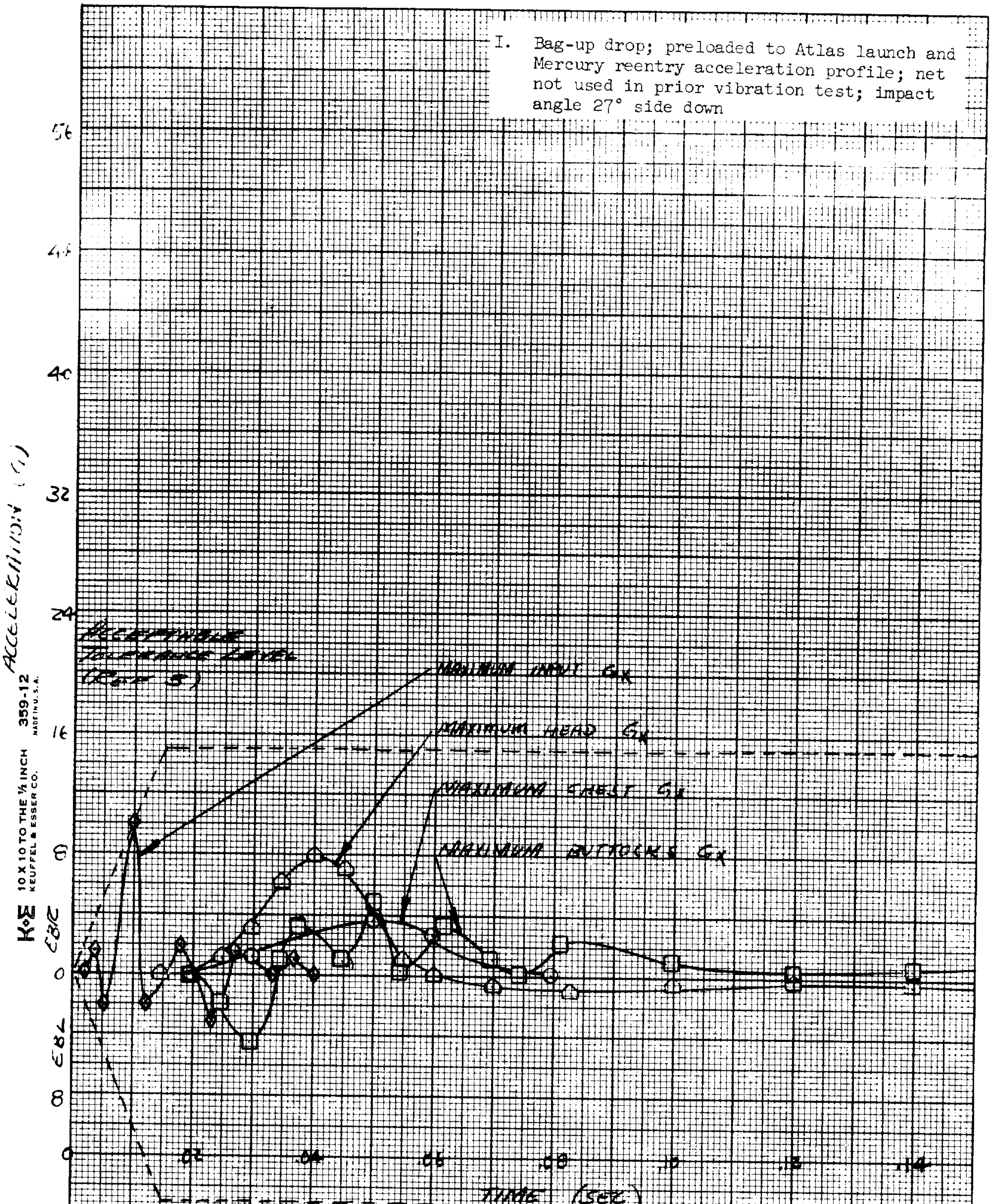

(a) EBI and EBO accelerations.

Figure 20I.- Capsule water drop tests; comparison of spacecraft and couch occupant acceleration-time histories.



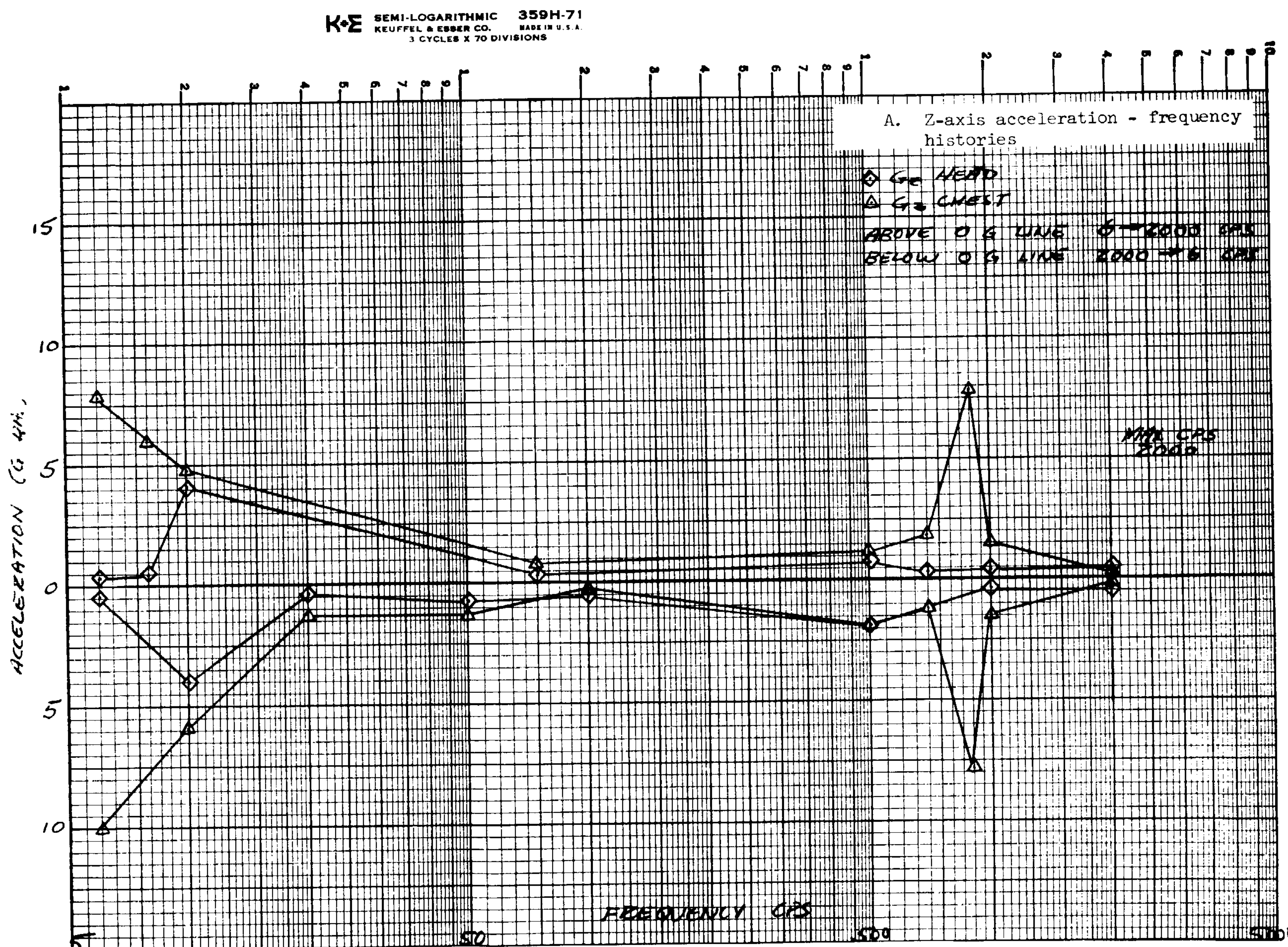

(b) EBU and EBD accelerations.

Figure 20I.- Continued



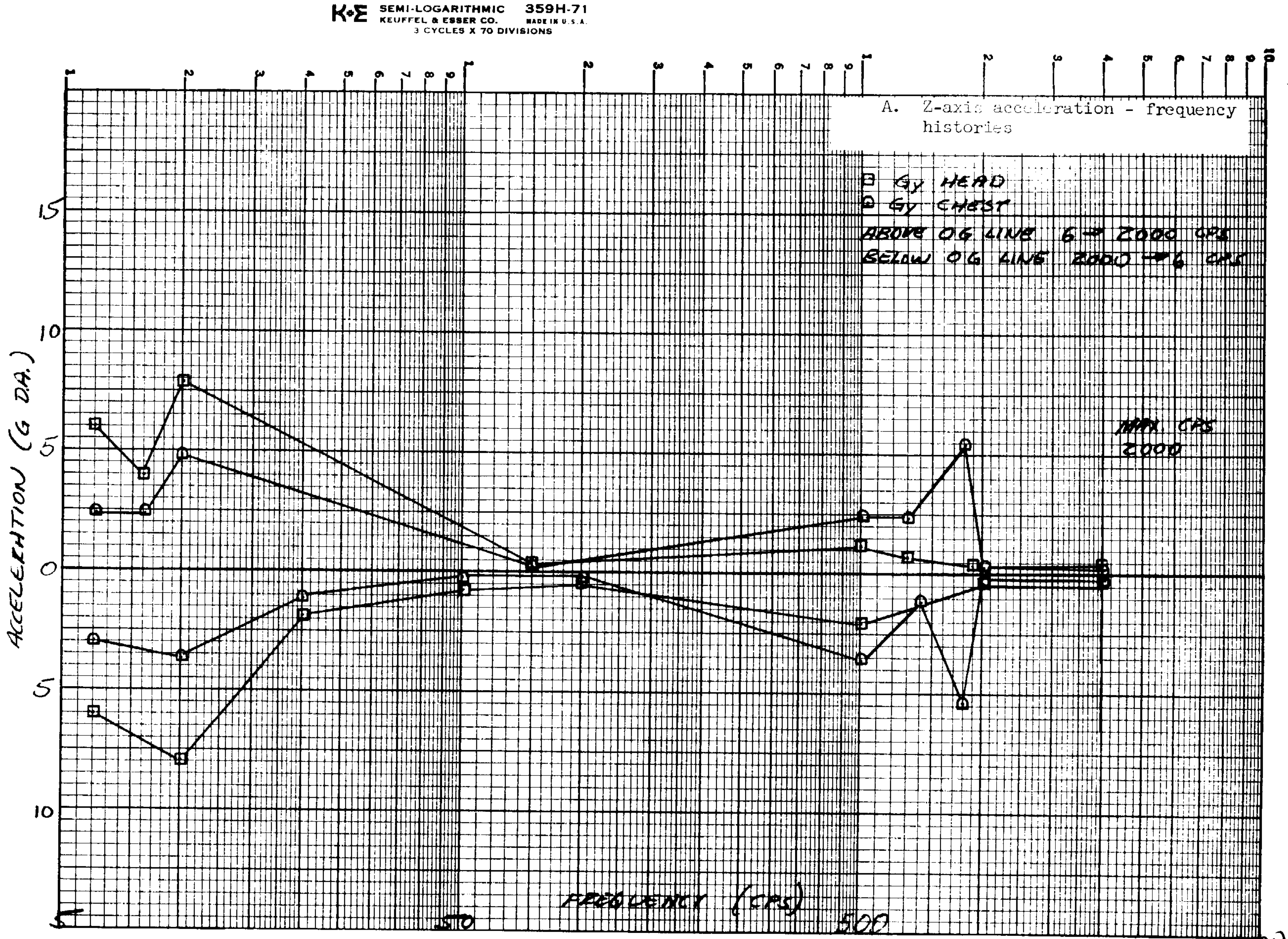

(c) EBR and EBL accelerations.

Figure 20I.- Concluded



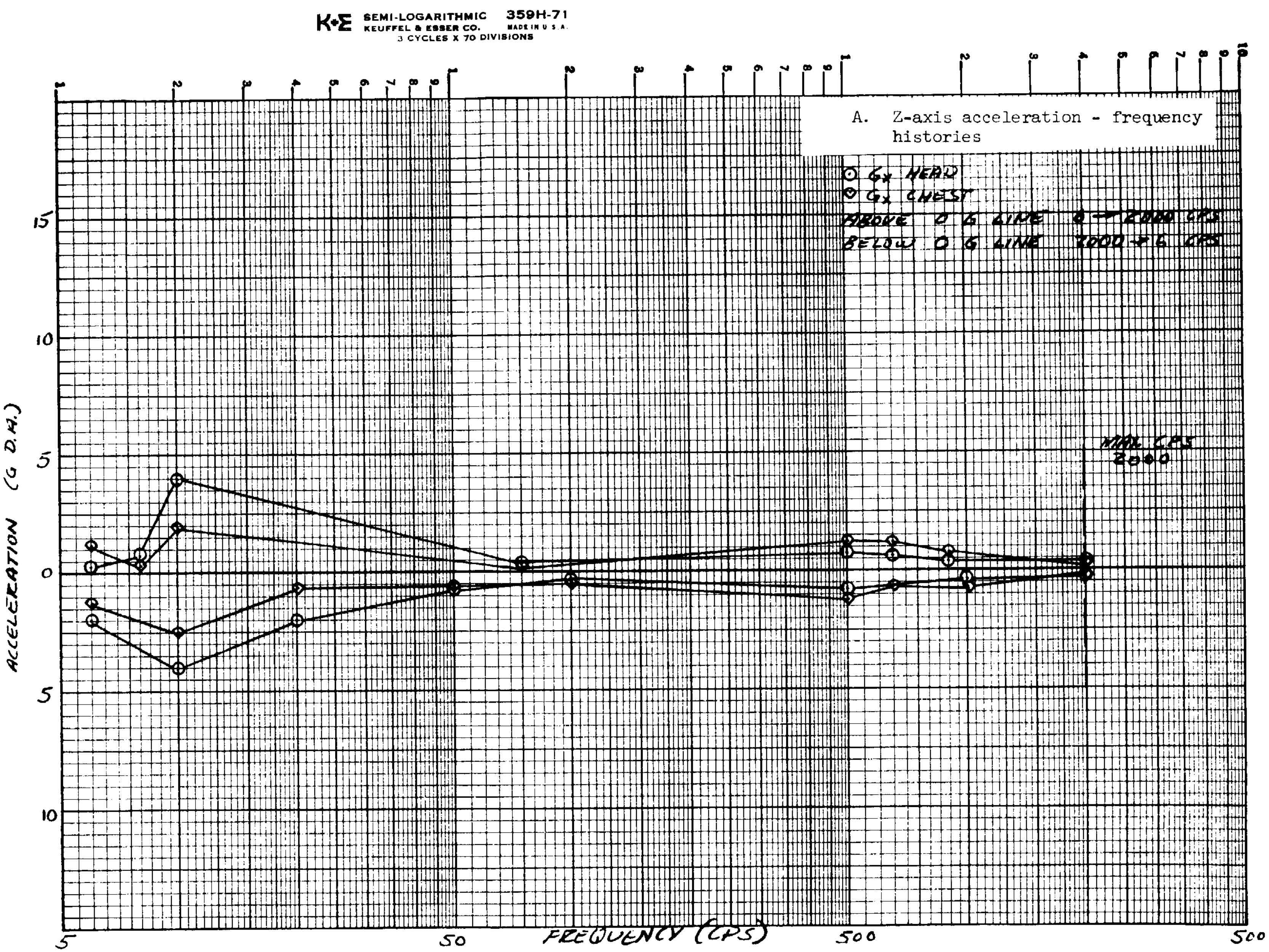

(a) $G_z$

Figure 21A.- Vibration test results



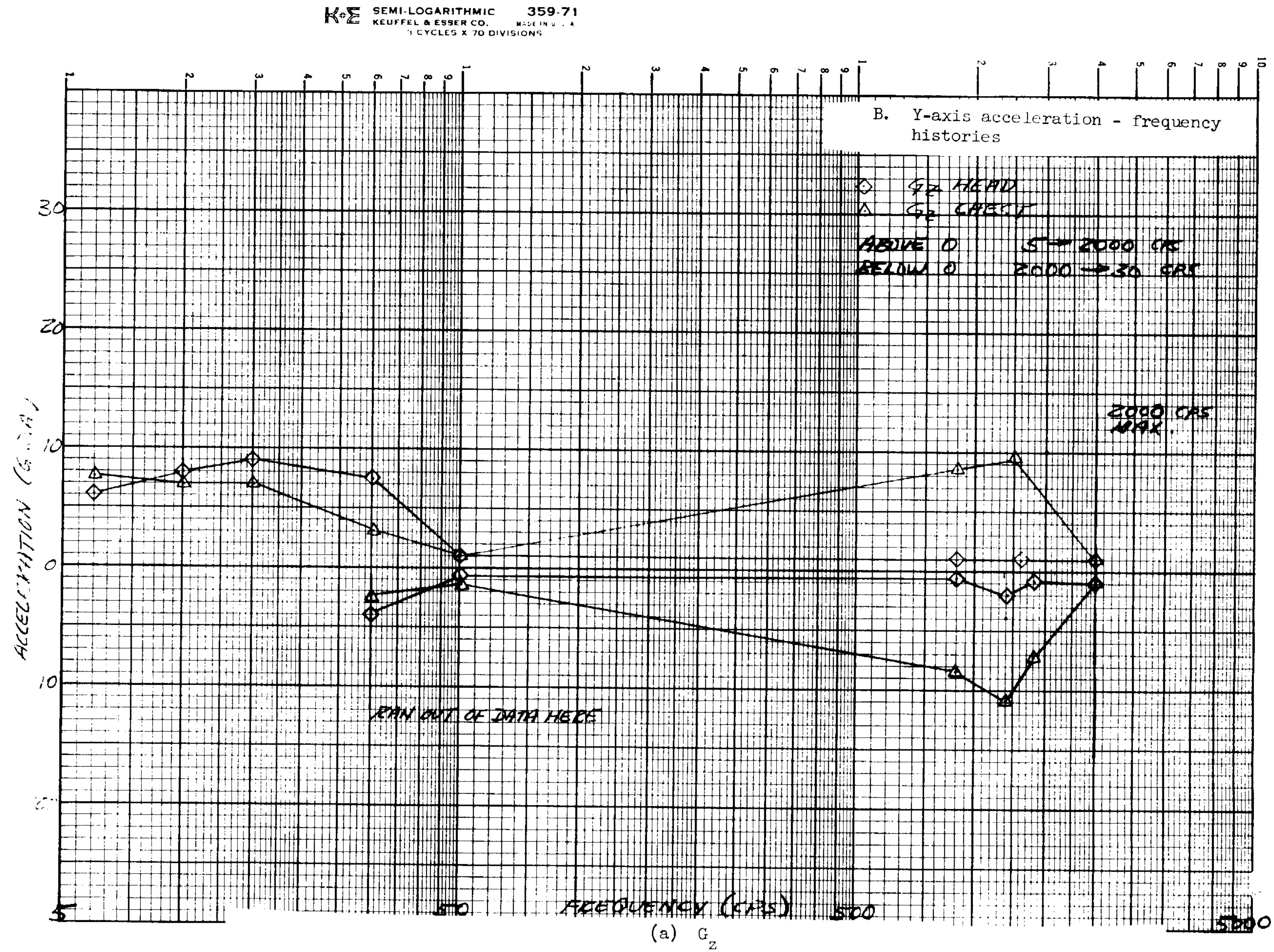

(b) $G_y$

Figure 21A.- Continued




(c) $G_x$

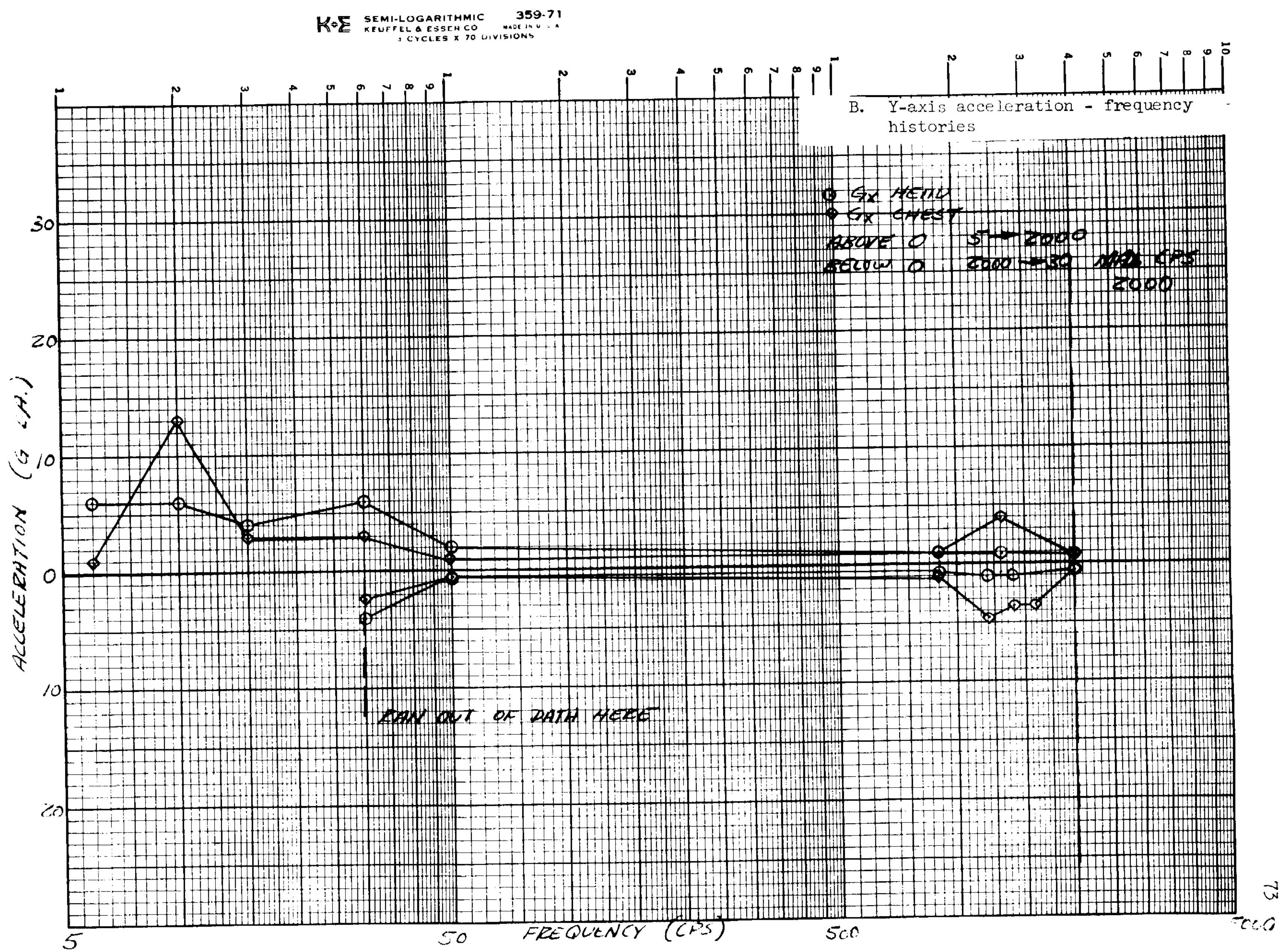
Figure 21A.- Concluded.




(a) $G_z$

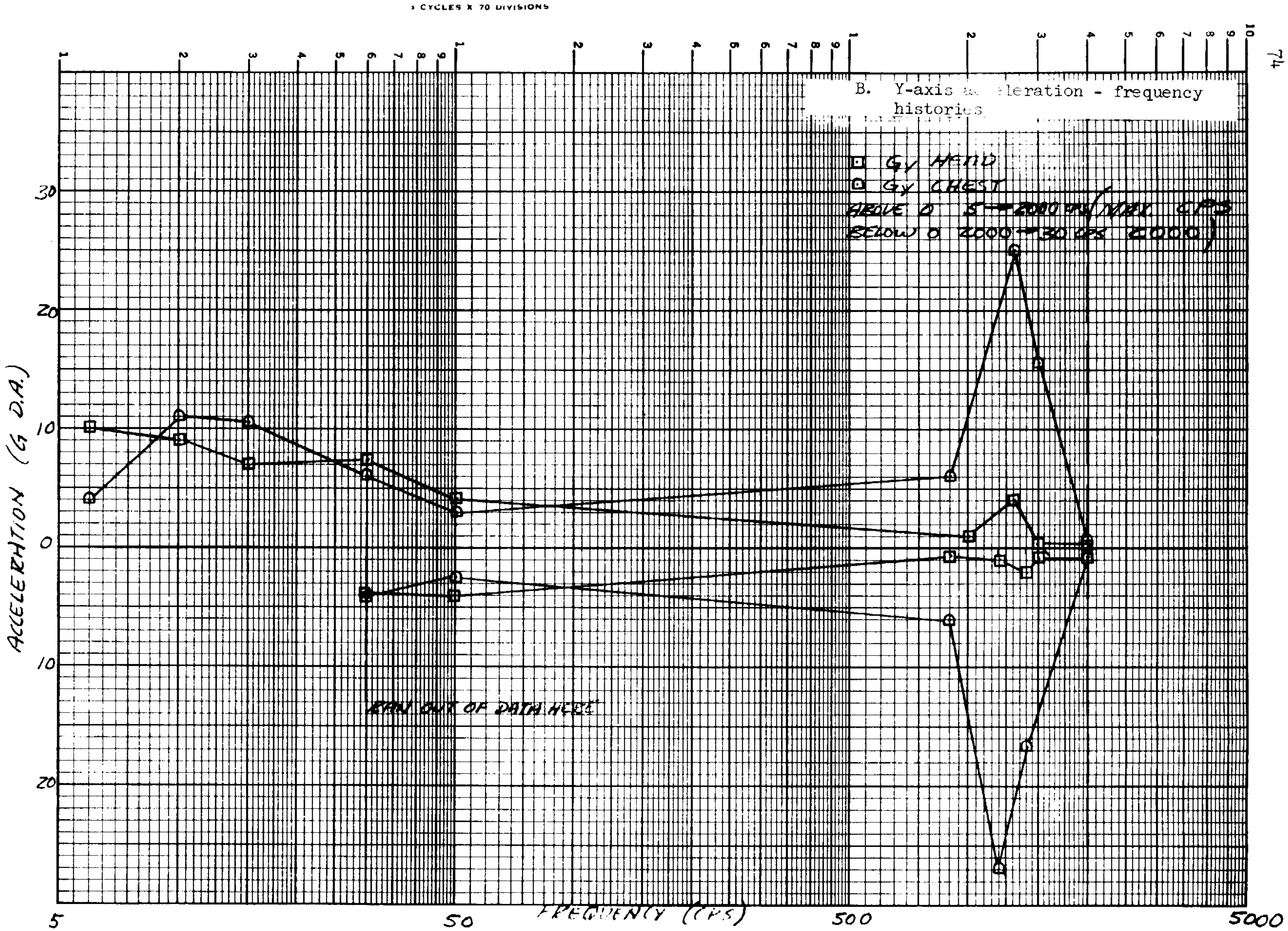
Figure 21B.- Vibration test results

B. Y-axis acceleration - frequency histories



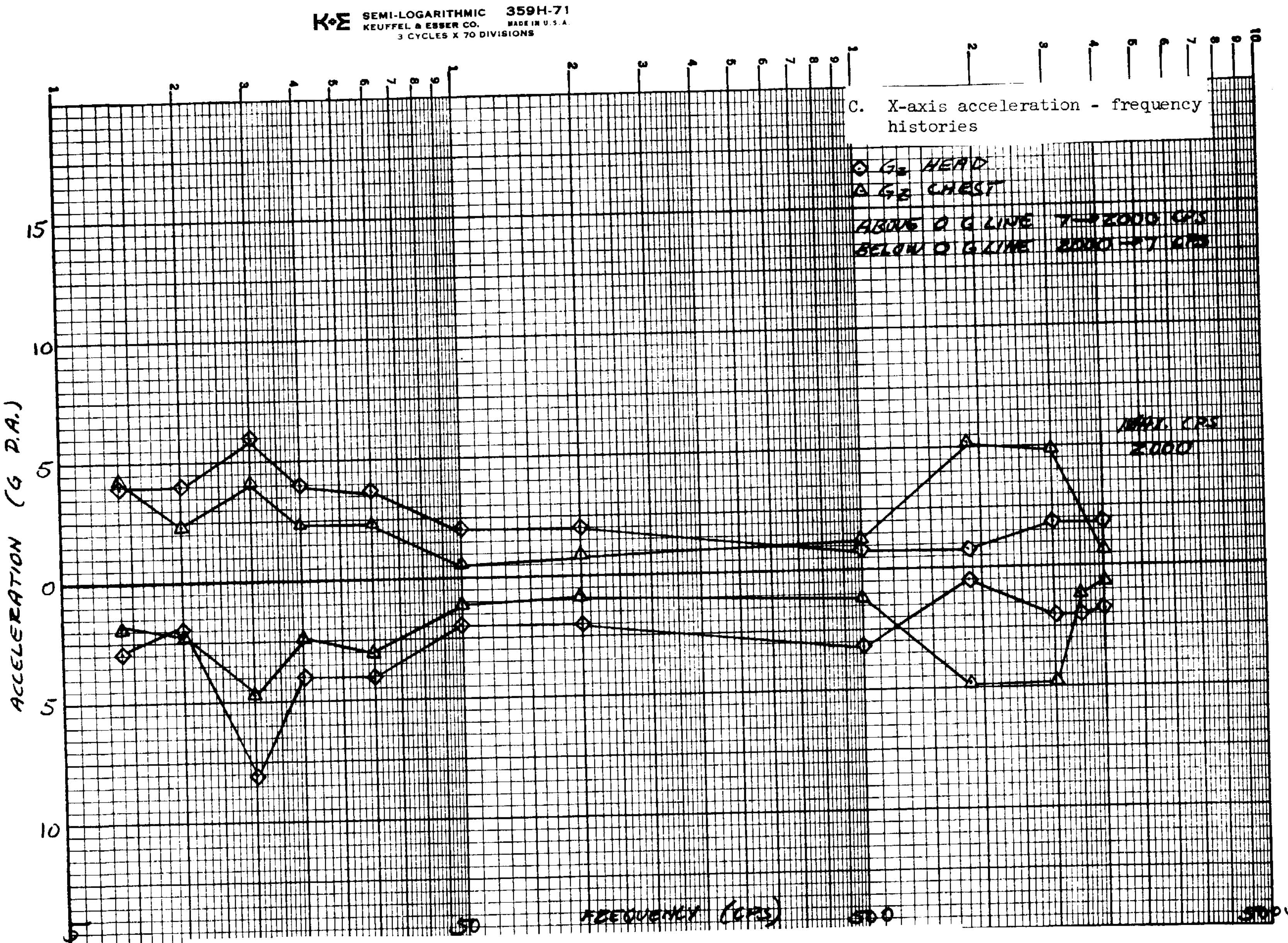

(b) $G_y$

Figure 21B.- Continued



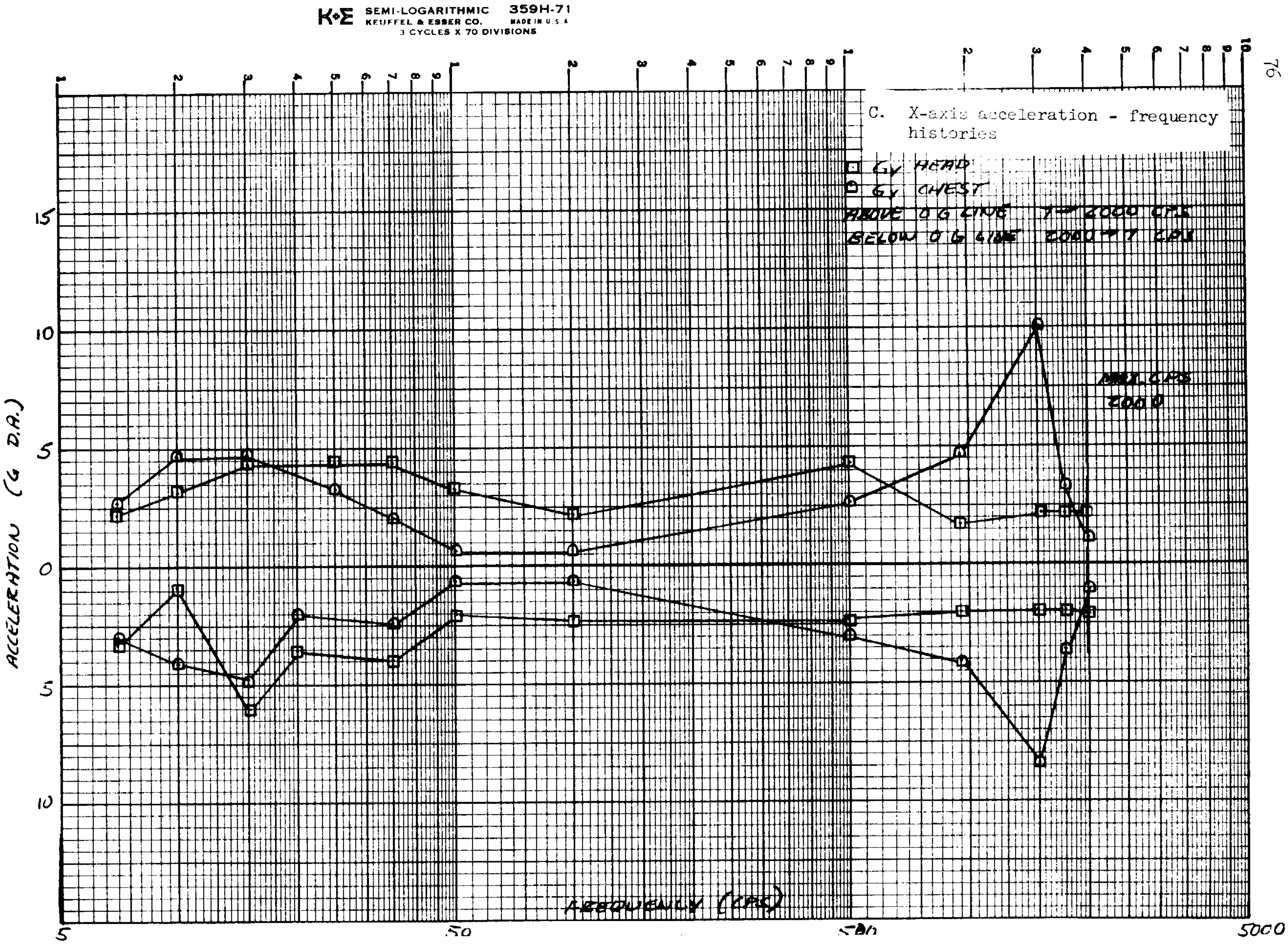

(c) $G_x$

Figure 21B.- Concluded.



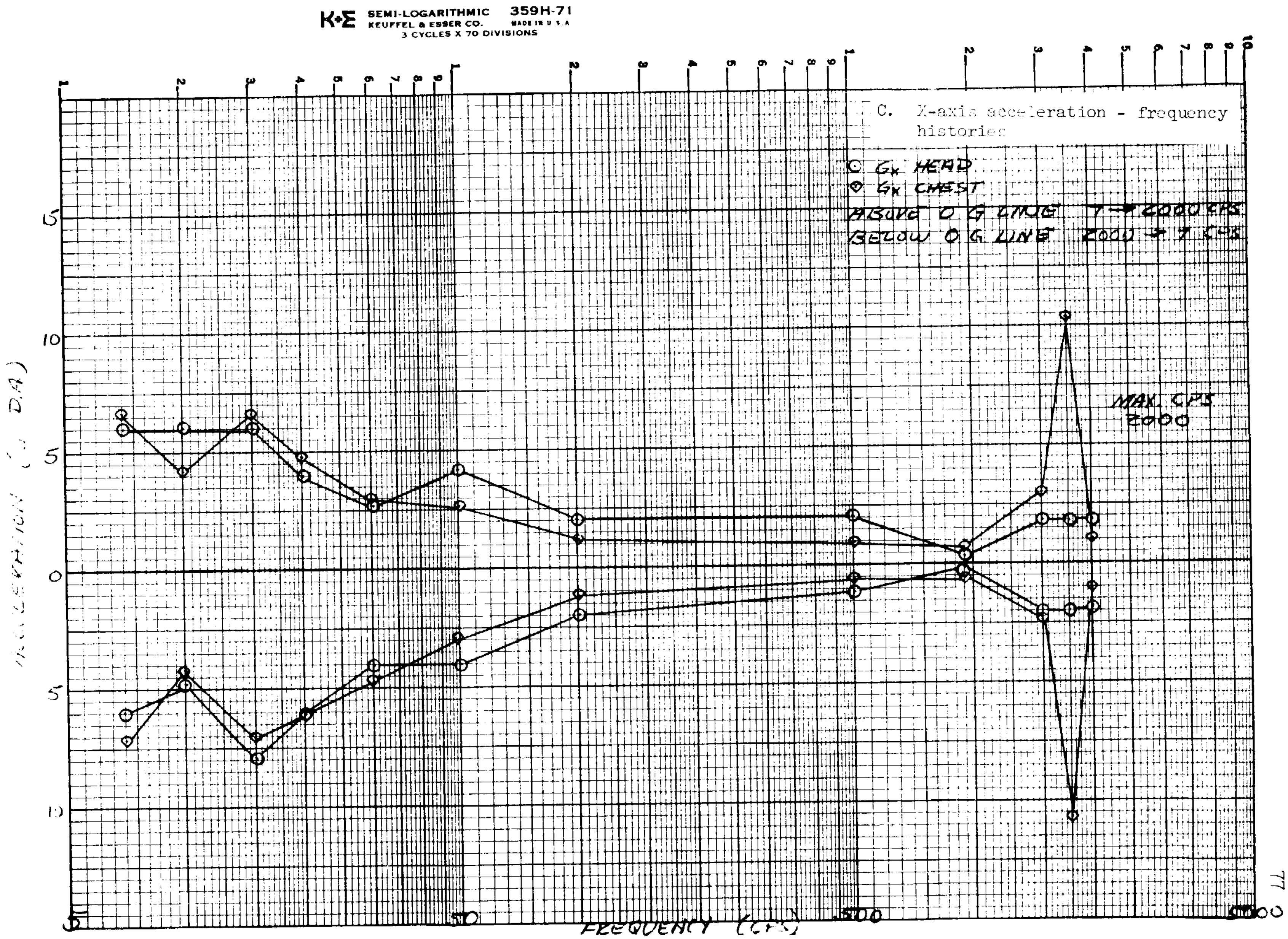

(a) $G_z$

Figure 21C.- Vibration test results




(b) $G_y$

Figure 21C.- Continued




(c) $G_x$

Figure 21C.- Concluded